PRINCIPLES AND PRACTICE OF FLOW METER ENGINEERING

By

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SIXTH EDITION

Revised and Enlarged

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PREFACE

While the orifice is one of the oldest known devices used for the measurement of rates of flow of fluids from vessels into the open air, its use in the case of closed-pipe flows does not appear to have been developed until comparatively recent years. The beginning of the investigation that later resulted in the development of the Foxboro Meter occurred in 1904 when Thos. R. Weymouth, of Oil City, Pa., installed a flange union with thin orifice plates in a line in series with a standard Pitot Tube of the Towl type, with the intention of studying its behavior and developing a simple rate-reading device to be used in measuring boiler fuel. This work was interrupted, however, and was not resumed until the Fall of 1911, when it was again taken up, resulting in the development of the Foxboro Orifice Meter.

The later work has been carried on by the American Gas Association, the Bureau of Standards, the Bureau of Mines and the A. S. M. E. In this book, we have correlated the available data on the subject in usable form.

Additional information on installation and operation of flow meters will be found in Book 55 (Liquid Meter Installation), and Book 50 (Gas Meter Installation).

But, in spite of every effort towards thoroughness of treatment and completeness of information, questions may have been overlooked. Our Engineers will always be glad to answer any questions that may arise concerning flow measurement.

The author wishes to acknowledge the contributions and assistance of his associate D. M. Hill, and many engineers of the M. W. Kellogg Co., E. B. Badger & Sons Co., Lummus Co., Universal Oil Products Co., The California Natural Gasoline Association, and others.

THE FOXBORO COMPANY

Fig. 8736
Foxboro Flow Meters at Tidewater Associated Oil Company, Ventura, California

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* Because of its similarity to the equation for F_s and because of possible confusion, the formula for B is not given elsewhere in this book.

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PART I

Liquid-Flow Measurement Computations

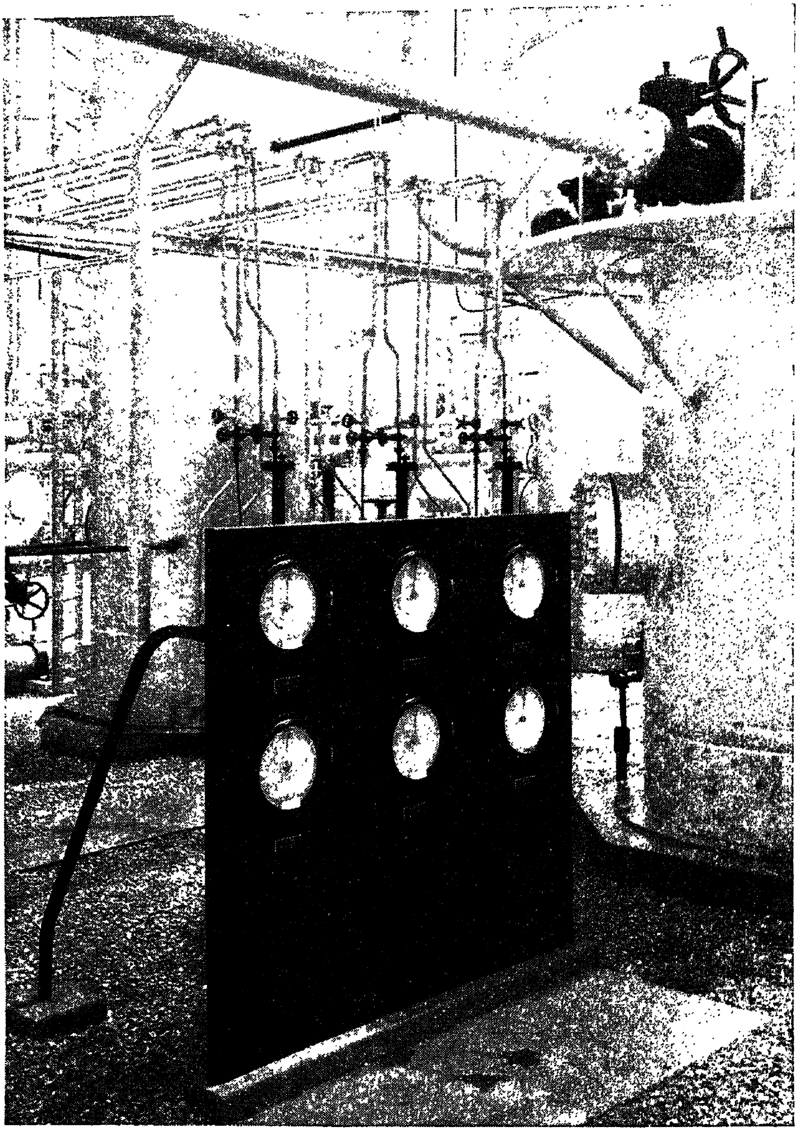


Fig. 8738
Foxboro Flow Meters in a Southwest distillate plant

LIQUID-FLOW COMPUTATIONS

The subject of liquid-flow computation has been divided into four sections.

The *First Section* gives general information necessary to a complete understanding of the subject of liquid flow measurement. Curves covering modern data on the thermal expansion of petroleum oils and curves of correction factors for compressibility of petroleum oils have been added to the contents of the previous five editions. Also, a new simplified method of computation is introduced.

The *Second Section* explains the methods of computation widely used in the oil industry, where it is common to use a standard-sized (1″, 2″, 3¼″, etc.) orifice and to obtain the flow by multiplying the square root of the differential pressure obtained from the chart record by a "coefficient" (a figure which is, practically speaking, the quantity of liquid that flows during a unit time when the differential pressure is one inch of water). It is a constant for a given orifice and given liquid temperature, etc.

The *Third Section* covers the computations necessary for use of a direct-reading Liquid-Flow Meter. The chart of this instrument reads directly in rate of flow. This is made possible by using a "flow scale chart" of the proper range and an orifice of a size such that the instrument reads correctly as long as conditions (specific gravity of liquid, etc.) remain constant.

To meet the wartime demand for data permitting the use of orifice plates in standard flange unions, a convenient method of correcting for vena contracta taps has been added. Computation instructions for use with pressure taps at 2½ pipe diameters upstream from the orifice and 8 pipe diameters down are also included.

The first three sections should be regarded as textbook material for study of the subject of flow measurement.

The *Fourth Section* has been added to fill the need for an operating section in which the arrangement, form of equations, operating curves, and tables were designed for most convenient everyday use. In this section, all of the unessential text has been omitted to eliminate the necessity of leafing through pages of extraneous matter to find the tables, curves, and charts for a specific problem.

Special data, not required in common flange-connected orifice computations (such as S curve for flow nozzles and corrections for vena contracta taps), are segregated in Section III, to permit the most convenient arrangement of Section IV for use on the more usual type of problem.

Examples of wide variety of problems have been included. It is suggested that the reader work out his own solution from the problem data before referring to the computation in the text. In this way, confidence in the ability to follow the correct procedure for any type of problem will be attained.

SECTION I
LIQUID FLOW
Volume Measurement

In the case of water at 60° F. flowing through a pipe in which there is a standard Foxboro orifice plate, the relationship between the differential pressure and the rate of flow is expressed by the equation $V = 327.2\ Ed^2\sqrt{h}$, in which V is the rate of flow in gallons per hour, E is the "efficiency" of the orifice (an experimentally derived figure which depends upon the ratio of orifice diameter to inside diameter of the line), d is the diameter of the orifice in inches, and h is the reading of a mercury differential gauge converted to equivalent inches of water.

When the mercury in a differential gauge is displaced, the fluid which displaces it adds to the differential existing at the orifice, thus causing high reading. The factor 327.2 includes the correction for this effect. Without this correction, the formula would be $V = 340\ Ed^2\sqrt{h}$.

The above equations apply to the simplest type of measurement problem: the flow of water at 60° F. Other liquids and other flowing temperatures require a formula which is more general than either of the above.

The formula for volume flow of liquid through an orifice is:—

$$\mathbf{V = MEd^2F_TF_G\sqrt{h}} \quad \textit{Equation 21}$$

V = rate of flow of liquid in units in which M is expressed.

M = a constant, the value of which depends on units of measurement. For instance, if the measurement is in gallons per hour M is 327.2. This value includes a correction for water on surface of the mercury. Factor F_G corrects for other liquids on surface of mercury, as well as for specific gravity of flowing liquid.

TABLE I

M

TIME	CU. FT.	U.S. GALLONS	BARRELS (42 GAL.)
Second	.01215	.09089	.002164
Minute	.7290	5.453	.1298
Hour	43.74	327.2	7.790
24-hour	1050	7853	187.0

E = efficiency of orifice. This figure is a function of d/D and may be obtained from the E table, page 66.

d = diameter of orifice in inches.

h = reading of differential gauge calibrated in inches of water with air on the surface of the mercury.

F_G = correction factor for gravity (see Alignment Chart, opposite page 7). For liquids of the density of water at 60° F., F_G is 1 and may be neglected.

F_T = correction for storage temperature =

$$\frac{\text{Sp. Gr. at flowing temp.}}{\text{Sp. Gr. at storage temp.}}$$

Equation 21 (also Equation 23, page 10) determines rate of flow; to obtain the total flow for any period it is necessary to multiply by time. For instance, a rate of flow of ten gallons per hour for six hours results in a total flow of sixty gallons.

Derivation of Liquid Flow Formula

Equation 21, Page 3, is derived from the basic formula for acceleration, $v = \sqrt{2gH} = \sqrt{\frac{2gh_a}{12}} = \sqrt{\frac{2 \times 32.16}{12}} \times \sqrt{h_a}$.

Multiplying by the area of the orifice, to obtain cubic feet and by 7.4805 to convert to gallons,

$$V = \frac{7.4805 \times 3600 \times \pi d^2}{4 \times 144} \times \sqrt{\frac{2 \times 32.16}{12}} \sqrt{h_a} \text{ gallons per hour.}$$

When the mercury in a differential gauge is displaced, the fluid displacing it adds to the differential at the orifice an amount equal to the head between the upper and lower surfaces of the displaced mercury. Hence: $G_f h_a = h - \frac{G_s h}{G_m}$ and $h_a = \left(\frac{1 - .0737\ G_s}{G_f}\right) h$.

Substituting this value of h_a, and introducing F_T, the factor which corrects the volume to storage temperature and E, the experimentally determined factor which corrects from theoretical to actual flow,

$$V = 340\ F_T \sqrt{\frac{1 - .0737\ G_s}{G_f}}\ Ed^2 \sqrt{h} \text{ or}$$

$$V = 327.2\ F_T \sqrt{\frac{1 - .0737\ G_s}{.9263\ G_f}}\ Ed^2 \sqrt{h}.$$

In the above:

H = actual differential in feet head of flowing liquid
h_a = actual differential in inches head of flowing liquid
h = differential registered by the meter, inches of water, dry calibration
G_m = specific gravity of mercury (water at 60°F = 1.0)
G_s = specific gravity of liquid displacing the mercury
G_f = specific gravity of the flowing fluid

MEASURING HOT LIQUIDS (VOLUME UNITS)

G_f is the specific gravity of the liquid as it passes through the orifice or primary device. A.P.I. and Baumé gravities are expressed at 60° F., and therefore must be corrected to flowing temperature by use of the equation: $G_f = G_b F_T$.

G_s is the specific gravity of the liquid displacing the mercury. Because its total effect on flow measurement is small, a wider tolerance is allowable in the determination of G_s. Unless the meter is subject to artificial heating or cooling, the displacing liquid comes to practically atmospheric temperature, and 60° F. may be considered a satisfactory average. If liquid seals are not used, the flowing fluid becomes the displacing liquid, and its specific gravity at 60° F. is used as G_s on the alignment chart or in the formula.

Determining Gravity Correction by Formula

In Equation:

$$F_G = \sqrt{\frac{1 - .0737G_s}{.9263G_f}} \quad \text{. . . . . } \textit{Equation 22}$$

F_G = correction for gravity

G_s = specific gravity of liquid displacing mercury in meter (water at 60° F. = 1.0).

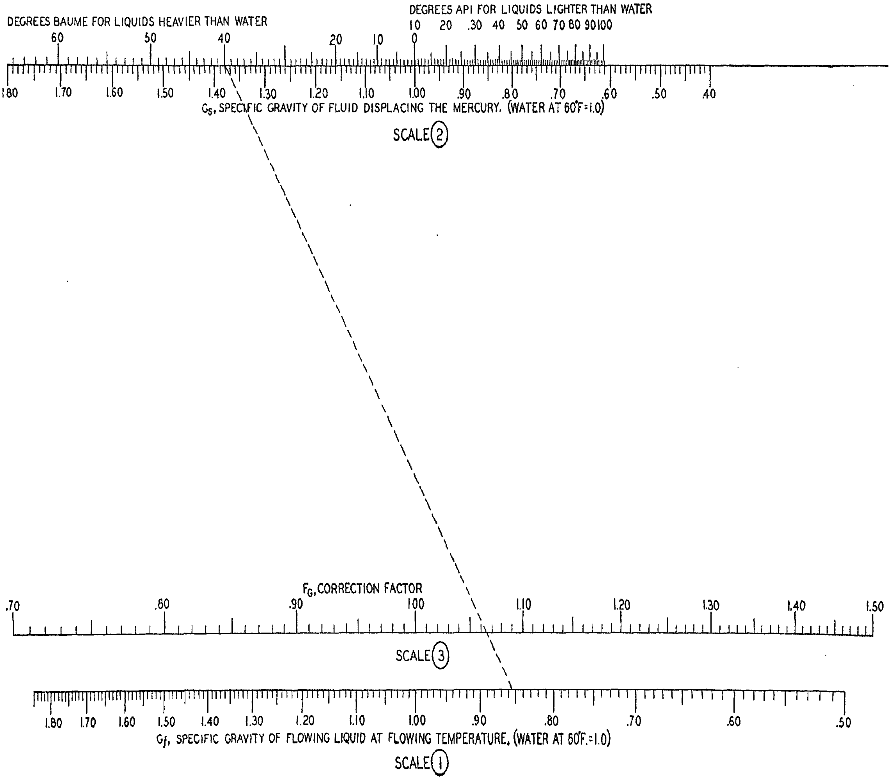
$G_f = G_b F_T$.

Determining Gravity Correction from Alignment Chart Fig. 3133

1. If A.P.I. gravity or Baumé gravity is given, look up G_b in tables on pages 19 to 21 and convert to G_f by the formula $G_f = G_b F_T$.

2. Set straight edge on specific gravity of flowing liquid (G_f) on Scale 1.

Alignment Chart, Fig. 3133



3a. If seal is used, set other end of straight edge at seal gravity (G_s) on Scale 2.

3b. If seal is not used, set other end of straight edge at A.P.I. or Baumé gravity of flowing fluid or at specific gravity of flowing fluid at 60° F. (G_b) on Scale 2.

4. Read correction factor F_G on Scale 3.

Example

Given: A.P.I. gravity = 25.7°
F_T = .95
G_s = 1.381

G_b = .9 (page 19)
G_f = .9 × .95 = .855
F_G = 1.065 (see reading on Scale 3 at dotted line).

Corrections for Storage Temperature

If F_T in Equation 21 is considered 1.0, V will represent the rate of flow of liquid at the temperature prevailing at the orifice.

In order to reduce to a storage temperature lower than the flowing temperature, it is necessary to multiply by a factor to correct for shrinkage. Since tank gaugings are usually corrected to volume at 60° F., orifice meter readings must be corrected to the same temperature in order to check.

Values of F_T for any liquid and any storage temperature may be derived from physical data showing density vs. temperature, by the following formula:

$$F_T = \frac{G_f}{G_b}$$

F_T = correction factor for temperature

G_f = specific gravity of flowing liquid at flowing temperature (water at 60° F. = 1.0)

G_b = specific gravity of flowing liquid at storage temperature (water at 60° F. = 1.0)

NEW WORKING EQUATIONS FOR PETROLEUM OILS OR WATER

A more convenient equation for use in petroleum oil or water calculations is obtained by substituting $F_sF_d\sqrt{F_T}$ for F_TF_G in Equation 21.

Derivation of New Working Formula (Volume Measurement)

Although the factor F_T is the obvious correction for temperature, thermal expansion also affects F_G, since G_t, which is used in the computation of F_G, is equal to G_bF_T.

The factors $F_T\,F_G$ may be rewritten as follows:

$$F_TF_G = F_T\sqrt{\frac{1 - .0737\ G_s}{.9263\ G_bF_T}} = \sqrt{F_T}\sqrt{\frac{1 - .0737\ G_s}{.9263\ G_b}}.$$

The quantity $\sqrt{\frac{1 - .0737\ G_s}{.9263\ G_b}}$ may be rewritten:

$$\sqrt{\frac{1 - .0737\ G_s}{1 - .0737\ G_b}}\quad\sqrt{\frac{1 - .0737\ G_b}{.9263\ G_b}}$$

Let $F_s = \sqrt{\frac{1 - .0737G_s}{1 - .0737G_b}}$ . . . . *Equation 17*

and $F_d = \sqrt{\frac{1 - .0737G_b}{.9263G_b}}$ . . . . *Equation 20*

Then $F_TF_G = F_sF_d\sqrt{F_T}$. See Section IV for nomenclature, tables, curves, etc.

It might appear, offhand, that this substitution would complicate rather than simplify the formula, since it contains one additional factor.

However, it will be noted that F_d is combined with $\sqrt{F_T}$ in one plot, Fig. 8638, page 58, and if no seals are used, $F_s = 1.0$ and may be omitted. If seals are used, F_s can be read from Alignment Chart Fig. 8635, page 57, or computed from Equation 17.

Other Liquids (Volume Measurement)

The above methods apply only to petroleum oils and to water for which the known predetermined expansion characteristics are included in the correction factors. In computing the flow of other liquids, for which it is necessary to obtain the expansion ratio from physical data reference books*, F_d may be read from pages 19 to 21 and $\sqrt{F_T}$ calculated.

New Working Equations for Any Liquids When G_f is Known (Volume Measurement)

A simplied method is recommended for obtaining the combined factor $F_sF_d\sqrt{F_T}$ when G_f, G_s, and G_b are known. The product of three factors, A, B, and $\frac{1}{G_b}$, each taken from a table is equal to $F_sF_d\sqrt{F_T}$. That is: $A \times B \times \frac{1}{G_b} = F_sF_d\sqrt{F_T}$. All three factors (A, B, and $\frac{1}{G_b}$) must be used whenever this method is employed.

* Suggested References: Smithsonian Physical Tables, Handbook of Chemistry and Physics, International Critical Tables, and Kent's Mechanical Engineers' Handbook.

LIQUID FLOW

Measurement by Weight

The weight of any quantity of liquid is equal to its volume times its density. So, in the flow equation, if we multiply the equation for volume rate of flow by the density of the flowing liquid (a constant times G_f), we obtain rate of flow in weight units.

"Weight Units" are not elastic, as is the case with volume units. For this reason the storage temperature correction which is used when measuring in volume units is unnecessary in connection with measurement by weight.

The above deviations from the procedure used in volume measurement make it advisable to deal with measurement in weight units as a separate subject.

The formula for flow (in weight units) of liquid through an orifice is

$$\mathbf{W = NEd^2F_GG_f\sqrt{h}} \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \textit{Equation 23}$$

W = rate of flow of liquid in units in which N is expressed.

N = constant depending on units of measurement. This value includes a correction for water on the surface of the mercury. Factor F_G corrects for other liquids on surface of mercury.

TABLE II

N

Pounds per second	N = .7578
Pounds per minute	N = 45.47
Pounds per hour	N = 2728
Pounds per 24 hours	N = 65470
Tons per 24 hours	N = 32.74

E = efficiency of orifice. This figure is a function of d/D and may be obtained from the E curve.

d = diameter of orifice in inches.

h = reading of differential gauge calibrated in inches of water with air on the surface of the mercury.

G_fF_G = correction for gravity. For liquids of the density of water at 60° F., G_fF_G is 1 and may be neglected.

G_f = specific gravity of flowing liquid at flowing temperature.

F_G = a correction factor for specific gravity of flowing liquid at flowing temperature. This value is the same as that used in volume measurement.

NEW WORKING EQUATIONS FOR PETROLEUM OILS OR WATER

As in the case of volume flow measurement, a more convenient method of computing weight flow of petroleum oils or water is obtained by substituting $F_sG_bF_d\sqrt{F_T}$ for G_fF_G in the formula.

Derivation of New Working Formula (Weight Measurement)

If we write the equation for weight flow in terms of F_T, we get $G_fF_G = G_bF_T\sqrt{\dfrac{1 - .0737G_s}{.9263G_bF_T}} = G_b\sqrt{F_T}\sqrt{\dfrac{1 - .0737G_s}{.9263G_b}}$. The quantity $\sqrt{\dfrac{1 - .0737G_s}{.9263G_b}}$ may be written $\sqrt{\dfrac{1 - .0737G_s}{1 - .0737G_b}}\sqrt{\dfrac{1 - .0737G_b}{.9263G_b}} = F_sF_d$. Hence, we may substitute $F_sG_bF_d\sqrt{F_T}$ for G_fF_G in the weight flow formula. See Section IV for nomenclature, tables, curves, etc.

When no seals are used $F_s = 1.0$ and may be omitted. For petroleum oils and water, the combined factor $G_bF_d\sqrt{F_T}$ has been plotted and can be obtained in a single operation.

New Working Equations for Any Liquid when G_f is Known (Weight Measurement)

A simplified method is recommended for obtaining the combined factor $F_s\,G_b\,F_d\sqrt{F_T}$ when G_f and G_s are known. Two factors, A and B, are taken from tables and the product is equal to $F_sG_bF_d\sqrt{F_T}$. That is: $A \times B = F_sG_bF_d\sqrt{F_T}$. Both factors, A and B, must be used whenever this method is employed.

THERMAL EXPANSION OF PETROLEUM PRODUCTS

Petroleum products are in most cases mixtures of hydrocarbon compounds. The expansion characteristics of two oils of the same A.P.I. gravity may differ substantially. Recent analyses on the subject indicate that the pseudo-critical temperature of such mixtures gives a better basis of correlation than A.P.I. gravity. Since data on pseudo-critical temperature are ordinarily not available by direct determination, a method has been provided for arriving at this value from a combination of A.P.I. gravity and molal average boiling point, Fig. 8654, page 15.

If the molal average boiling point or other information permitting the determination of pseudo-critical temperature is available, we recommend the use of Fig. 8629, page 16. These curves, as are all others in this handbook dealing with the thermal expansion of petroleum oils, are based on densities at the flowing temperature and critical pressure. They are terminated where they become too steep for readability. Values may be extrapolated by extending the curves to the point where flowing temperature equals pseudo-critical temperature. At this point $\sqrt{F_T} = \sqrt{\frac{G_b}{G_c}}$ in which G_c = critical specific gravity (water at 60° F. = 1.0).

For temperatures up to 70% of pseudo-critical (°Abs.) petroleum products in the liquid state are practically incompressible, and these curves may be used without correction for pressure. At temperatures above 70% of pseudo-critical (°Abs.) a compressibility correction should be applied. See Fig. 8631, page 18.

T_R = Absolute flowing temperature ÷ absolute pseudo-critical temperature, $T_c + 460$.

P_R = Absolute flowing pressure ÷ absolute pseudo-critical pressure, P_c.

To apply the compressibility correction from Fig. 8631, page 18, insert the factor F_D as a multiplier for $\sqrt{F_T}$.

TABLE IV
Useful Physical Data

		°A.P.I.	G_b	P_c lbs/sq. in. Absolute	T_c, ° F.	G_c
Methane	CH_4	....	....	673	−116.5	.162
Ethane	C_2H_6	....	....	708	+ 90.1	.21
Propane	C_3H_8	146.5	.509	617	206.2	....
n-Butane	C_4H_{10}	110.8	.584	551	305.6	....
Isobutane	C_4H_{10}	119.4	.564	544	273.2	....
n-Pentane	C_5H_{12}	92.8	.631	485	387.0	.232
Isopentane	C_5H_{12}	94.9	.625	482	370.0	.234
n-Hexane	C_6H_{14}	81.6	.664	434	454.6	.234
n-Heptane	C_7H_{16}	74.2	.688	397	512.6	.234
n-Octane	C_8H_{18}	68.6	.707	361	564.8	.234
2, 2, 4-Trimethyl Pentane	C_8H_{18}	71.8	.696	360	530.6	....
n-Nonane	C_9H_{20}	64.5	.722	337	612.0	....
n-Decane	$C_{10}H_{22}$	61.3	.734	312	655.0	....
Ethene	C_2H_4	....	....	749	49.5	.22
Propene	C_3H_6	....	....	668	196.8	....
Butene-1	C_4H_8	104.3	.600	....	291.2	....
Butene-2	C_4H_8	98.6	.615	....	311.0	....
Isobutene	C_4H_8	103.2	.603	....	290.3	....
Pentene-1	C_5H_{10}	86.9	.648	595	394.2	....
Pentene-2	C_5H_{10}	84.5	.655	....	376.9	....
Hexene-1	C_6H_{12}	76.9	.679	....	470.3	....
Heptene-1	C_7H_{14}	70.1	.702	....	....	....
Octene-1	C_8H_{16}	65.0	.720	....	580.6	....
Nonene-1	C_9H_{18}	61.0	.735	....	....	....
Decene-1	$C_{10}H_{20}$	57.7	.748	....	....	....
Benzene	C_6H_6	28.9	.882	700	551.3	....
Toluene	C_7H_8	31.1	.870	611	609.1	....
Acetylene	C_2H_2	....	....	911	96.8	.231
Cyclohexane	C_6H_{12}	49.2	.783	594	537.8	.270
Styrene*	C_8H_8	23.5	.913	....	....	....
1, 3-Butadiene*	C_4H_6	94.5	.626	....	....	....

REFERENCE: "Physical Constants of Low Boiling-Point Hydrocarbons." By Robert Matteson and W. S. Hanna, Research and Development Department, Standard Oil Company of California. (*The Oil and Gas Journal*, May 21, 1942.)

*REFERENCE: Garnes, Adams, Stuchell — Mellon Institute of Industrial Research. "Storage and Handling of Butadiene, Isobutylene, Styrene and Acrylonitrile." (*Petroleum Refiner*, October, 1942.)

Determining Pseudo-Critical Temperature

The pseudo-critical temperature of a hydrocarbon mixture of a given A.P.I. gravity may be read from Fig. 8654 if the molal average boiling point is known. Charts are available for deriving pseudo-critical temperature from viscosity, viscosity index, aniline point or hydrogen content.

Curves in Working Section

In order to develop a quick, convenient means of calculating everyday refinery flow problems, we have assumed pseudo-critical temperatures which give an average of the temperature expansion ratios shown by the most reliable correlations of A.P.I. gravity vs. thermal expansion data which we have been able to obtain. The pseudo-critical temperatures (T_c) on which the values of F_T used in the curves on pages 58 (Fig. 8638) and 59 (Fig. 8637) were based, are given in the following table:

TABLE III

A. P. I.	T_c (°F.)	A. P. I.	T_c (°F.)
10	1400	60	615
20	1200	70	545
30	960	80	470
40	795	90	405
50	690	100	350

The data in the curves plotted on the basis of A.P.I. gravity apply to normal mixtures found in virgin paraffin base stocks. For asphalt base or cracked stocks, the rate of expansion is greater, and the value of F_T is lower.

For measurement of cracked residuum when information for determining pseudo-critical temperature is available, we recommend that the values of $\sqrt{F_T}$ be taken from Fig. 8629 (page 16).

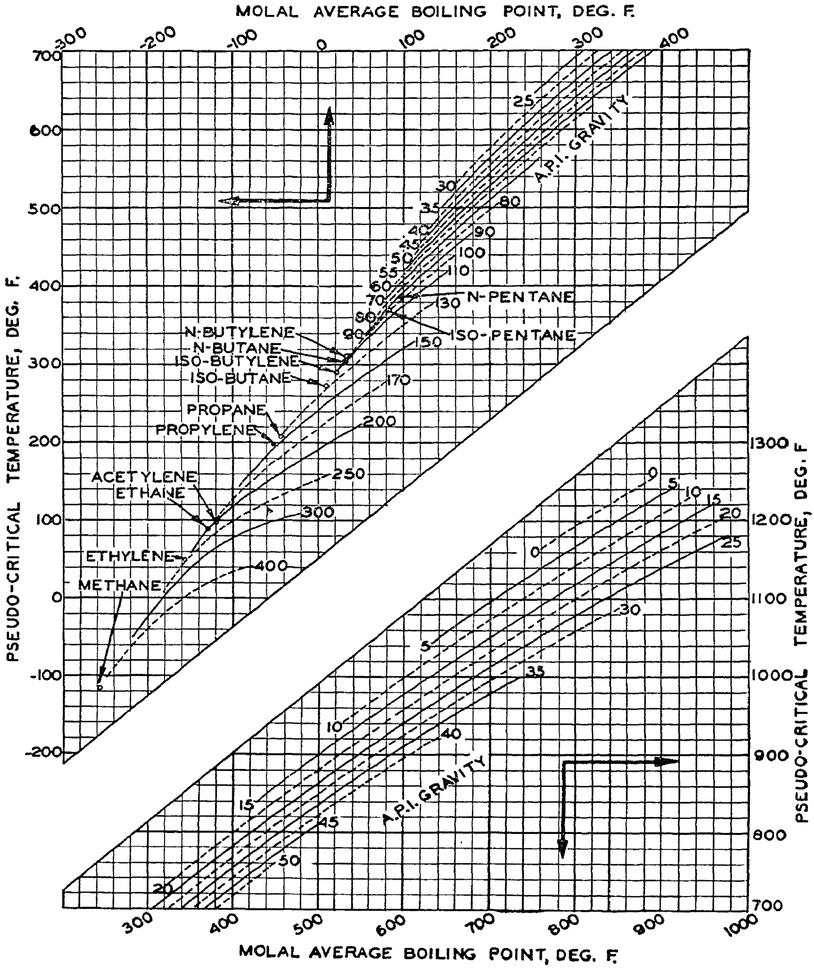


Fig. 8654

Pseudo-Critical Temperature, T_c

From "Boiling Points and Critical Properties of Hydrocarbon Mixtures," by R. L. Smith and K. M. Watson, Universal Oil Products Co. (*Industrial & Engineering Chemistry*, December, 1937).

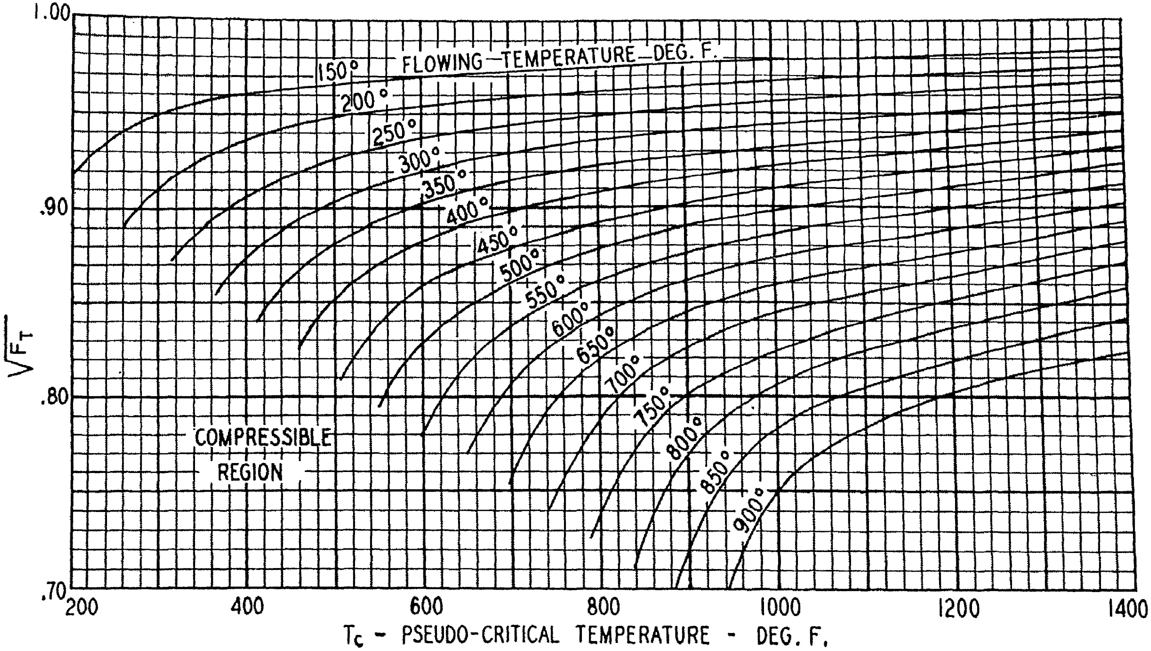


Fig. 8629

TEMPERATURE CORRECTIONS FOR PETROLEUM PRODUCTS, $\sqrt{F_T}$

Derived from "High Temperature Expansion of Petroleum Fractions" by K. M. Watson, E. F. Nelson, and George B. Murphy, Universal Oil Products Co. (*Oil and Gas Journal*, November 12, 1936.)

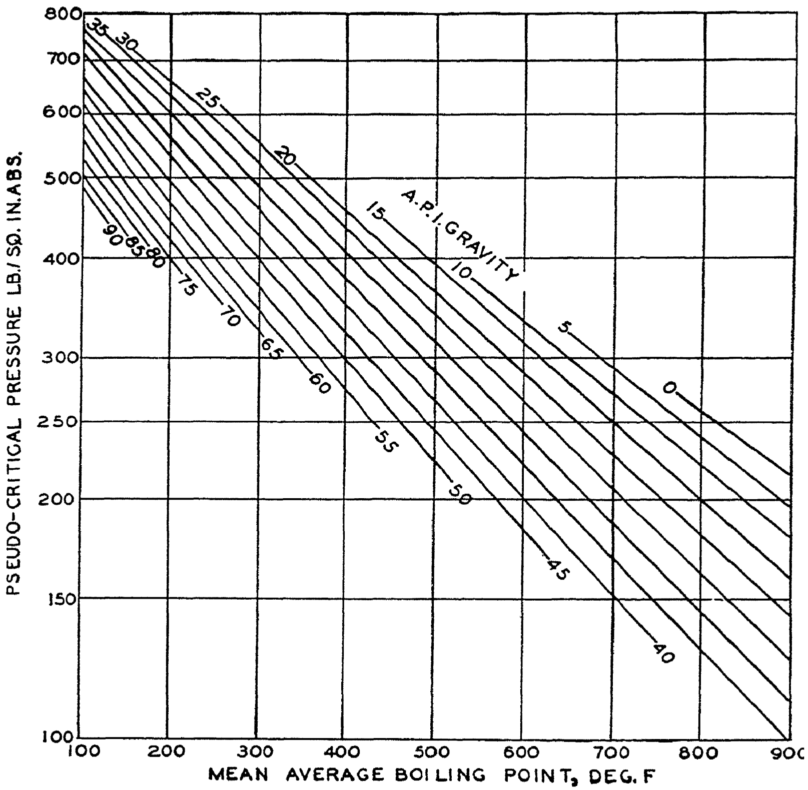
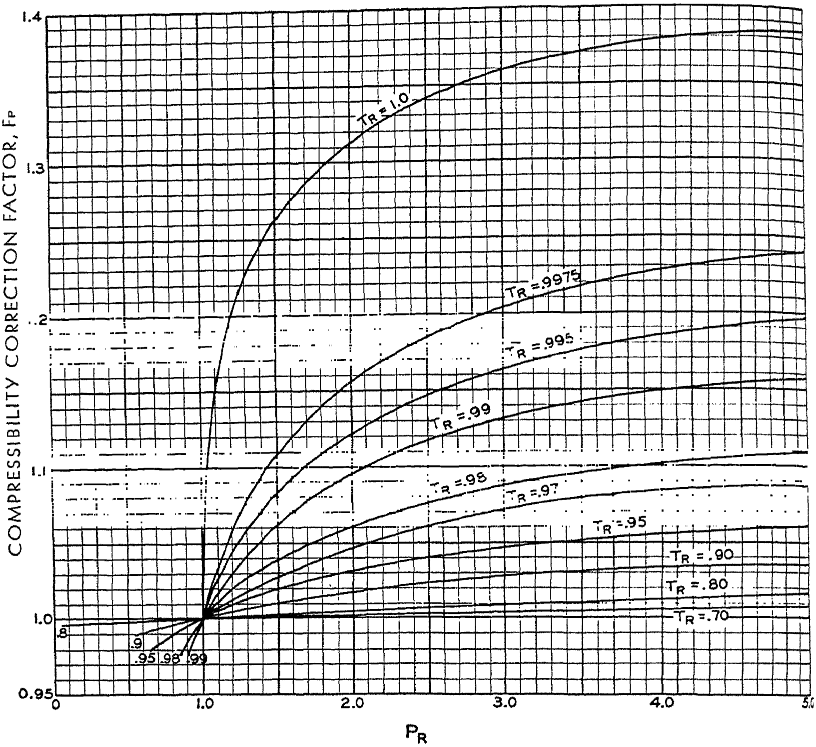


Fig. 8642

Pseudo-Critical Pressures, P_c

From "Boiling Points and Critical Properties of Hydrocarbon Mixtures" by R. L. Smith and K. M. Watson, Universal Oil Products Co. (*Industrial & Engineering Chemistry*, December, 1937.)



CORRECTION FACTOR — FP

Fig. 8631

Compressibility of Petroleum Products

Derived from "High Temperature Expansion of Petroleum Fractions" by K. M. Watson, E. F. Nelson, and George B. Murphy, Universal Oil Products Co. (*Oil & Gas Journal*, November 12, 1936.)

TABLE V
F_d
Correction Factors for Gravity
Petroleum Products

Deg. API Oils	Specific Gravity G_b	Factor F_d	Deg. API Oils	Specific Gravity G_b	Factor F_d
10	1.0000	1.000	46	.7972	1.129
11	.9930	1.004	47	.7927	1.132
12	.9861	1.008	48	.7883	1.136
13	.9792	1.011	49	.7839	1.139
14	.9725	1.015	50	.7796	1.142
15	.9659	1.019	51	.7753	1.146
16	.9593	1.023	52	.7711	1.149
17	.9529	1.026	53	.7669	1.152
18	.9465	1.030	54	.7628	1.156
19	.9402	1.034	55	.7587	1.159
20	.9340	1.037	56	.7547	1.162
21	.9279	1.041	57	.7507	1.166
22	.9218	1.045	58	.7467	1.169
23	.9159	1.048	59	.7428	1.172
24	.9100	1.052	60	.7389	1.175
25	.9042	1.056	61	.7351	1.179
26	.8984	1.059	62	.7313	1.182
27	.8927	1.063	63	.7275	1.185
28	.8871	1.066	64	.7238	1.188
29	.8816	1.070	65	.7201	1.191
30	.8762	1.074	66	.7165	1.195
31	.8708	1.077	67	.7128	1.198
32	.8654	1.081	68	.7093	1.201
33	.8602	1.084	69	.7057	1.204
34	.8550	1.088	70	.7022	1.207
35	.8498	1.091	71	.6988	1.211
36	.8448	1.095	72	.6952	1.214
37	.8398	1.098	73	.6919	1.217
38	.8348	1.102	74	.6886	1.220
39	.8299	1.105	75	.6852	1.223
40	.8251	1.109	76	.6819	1.226
41	.8203	1.112	77	.6787	1.229
42	.8155	1.115	78	.6754	1.232
43	.8109	1.119	79	.6722	1.235
44	.8063	1.122	80	.6690	1.239
45	.8017	1.126			

Continued on page 20

TABLE V—*Continued*

F_d

Correction Factors for Gravity

Petroleum Products

Deg. API Oils	Specific Gravity G_b	Factor F_d	Deg. API Oils	Specific Gravity G_b	Factor F_d
81	.6659	1.242	116	.5717	1.345
82	.6628	1.245	117	.5694	1.348
83	.6597	1.248	118	.5671	1.350
84	.6566	1.251	119	.5647	1.353
85	.6536	1.254	120	.5626	1.356
86	.6506	1.257	121	.5604	1.359
87	.6476	1.260	122	.5582	1.362
88	.6446	1.263	123	.5560	1.365
89	.6417	1.266	124	.5538	1.367
90	.6388	1.269	125	.5517	1.370
91	.6360	1.272	126	.5495	1.373
92	.6331	1.275	127	.5474	1.375
93	.6303	1.278	128	.5453	1.378
94	.6275	1.281	129	.5432	1.381
95	.6247	1.284	130	.5411	1.384
96	.6220	1.287	131	.5391	1.387
97	.6193	1.290	132	.5370	1.389
98	.6166	1.293	133	.5350	1.392
99	.6139	1.296	134	.5330	1.395
100	.6112	1.299	135	.5310	1.397
101	.6086	1.302	136	.5290	1.400
102	.6060	1.304	137	.5270	1.403
103	.6034	1.307	138	.5251	1.406
104	.6009	1.310	139	.5231	1.408
105	.5983	1.313	140	.5212	1.411
106	.5958	1.316	141	.5193	1.414
107	.5934	1.319	142	.5184	1.417
108	.5908	1.322	143	.5155	1.419
109	.5884	1.325	144	.5136	1.422
110	.5859	1.327	145	.5117	1.424
111	.5835	1.330	146	.5099	1.427
112	.5811	1.333	147	.5081	1.430
113	.5787	1.336	148	.5063	1.433
114	.5764	1.339	149	.5045	1.435
115	.5740	1.342	150	.5027	1.438

TABLE VI
F_d
Correction Factors for Gravity
Acid and Salt Solutions

Deg. B.E. Heavy Liquids	Specific Gravity G_b	Factor F_d	Deg. B.E. Heavy Liquids	Specific Gravity G_b	Factor F_d
1	1.0069	.996	36	1.3303	.856
2	1.0140	.993	37	1.3426	.851
3	1.0211	.989	38	1.3551	.847
4	1.0284	.985	39	1.3679	.842
5	1.0357	.981	40	1.3810	.838
6	1.0432	.977	41	1.3942	.834
7	1.0507	.974	42	1.4078	.829
8	1.0584	.970	43	1.4216	.825
9	1.0662	.966	44	1.4356	.820
10	1.0741	.962	45	1.4500	.815
11	1.0821	.958	46	1.4646	.811
12	1.0902	.954	47	1.4796	.806
13	1.0985	.950	48	1.4948	.802
14	1.1069	.946	49	1.5104	.797
15	1.1154	.943	50	1.5263	.792
16	1.1240	.939	51	1.5426	.788
17	1.1328	.935	52	1.5591	.783
18	1.1417	.931	53	1.5761	.778
19	1.1508	.927	54	1.5934	.773
20	1.1600	.923	55	1.6111	.768
21	1.1694	.918	56	1.6292	.764
22	1.1789	.914	57	1.6477	.759
23	1.1885	.910	58	1.6667	.754
24	1.1983	.906	59	1.6860	.749
25	1.2083	.902	60	1.7059	.744
26	1.2185	.898	61	1.7262	.739
27	1.2288	.894	62	1.7470	.734
28	1.2393	.890	63	1.7683	.729
29	1.2500	.886	64	1.7901	.724
30	1.2609	.881	65	1.8125	.718
31	1.2719	.877	66	1.8354	.713
32	1.2832	.871	67	1.8590	.708
33	1.2946	.869	68	1.8831	.703
34	1.3063	.863	69	1.9079	.697
35	1.3182	.860	70	1.9333	.692

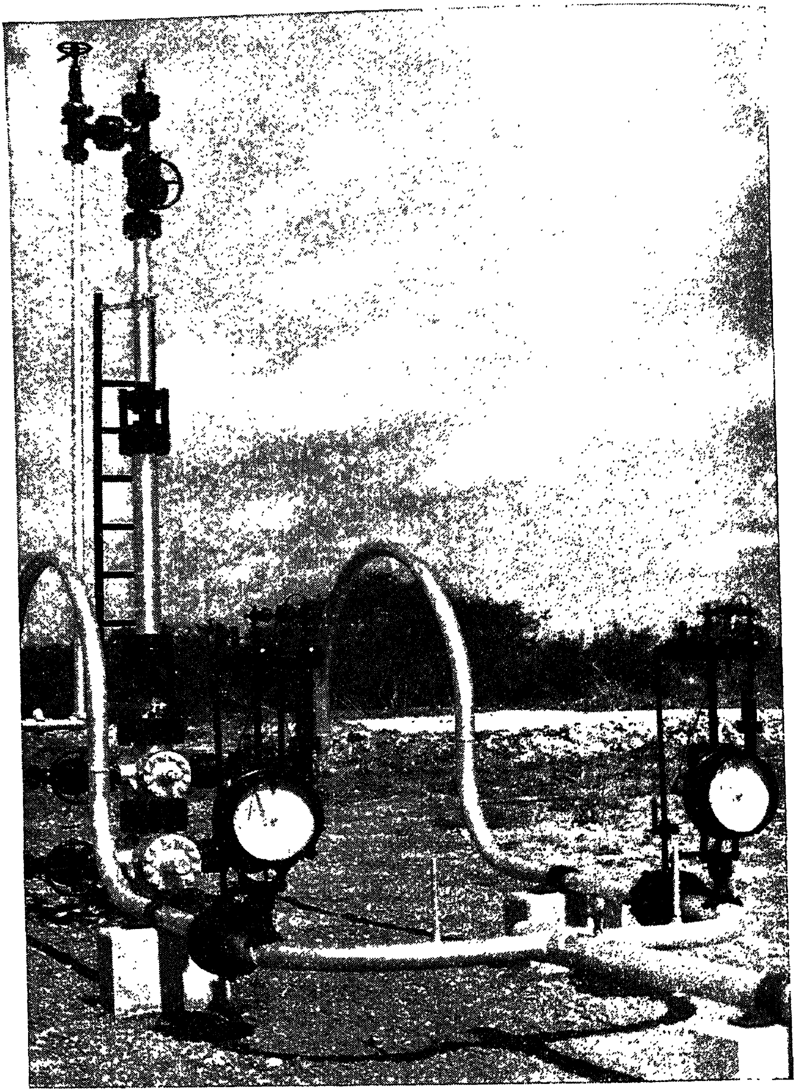


Fig. 8739

Foxboro Flow Meters at La Gloria Corporation, La Gloria, Texas

SECTION IIa

FLOW MEASUREMENT USING STANDARD SIZED ORIFICES

This Section explains the methods of computation widely used in the oil industry where it is common to use a standard-sized (1″, 2″, 3¼″, etc.) orifice, and to obtain the flow by multiplying the square root of the differential pressure obtained from the chart record by a "coefficient" (a figure which is, practically speaking, the quantity of liquid that flows through the orifice during a unit time when the differential pressure is one inch of water). It is a constant for a given orifice and given liquid temperature, etc.

In the oil industry the flexibility of capacity obtained by the use of such orifices often more than counterbalances the convenience of the direct-reading meter. In the following section we give directions for choosing the proper sized orifice and we have simplified the computation of coefficients to the multiplication of a number of factors, each of which may be taken from a table. All of the corrections necessary for accurate measurement of ordinary liquids may be found in these tables. In case of liquids of high viscosity, see page 47.

Many large meter users have found it advantageous to make use of standard-sized orifices and at the same time use a flow scale chart to secure a semi-direct-reading meter. The 0–10 or 0–100 flow scale chart is used with a multiplier which embraces the coefficient of the even-sized orifice times the correction factors for flowing conditions. Method of deriving the chart factor for any flow chart will be found on page 25.

Choice of Orifice Size

FLOW-CURVE FOR LIQUIDS

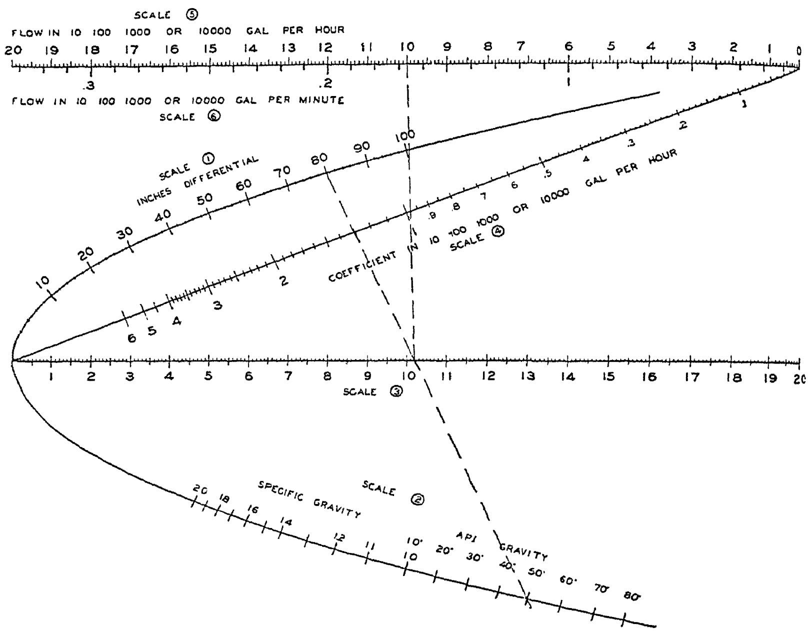


CHART B Fig. 2805

To find proper orifice for given flow conditions.

1. Place straight edge from differential on Scale 1 to gravity on Scale 2 and read Scale 3.
2. Place straight edge on reading on Scale 3 and flow on Scale 5 or 6 and read coefficient on Scale 4.
3. Choose orifice from Table VII, page 67, with coefficient slightly larger than reading on Scale 4.

Example

Find orifice size for 6″ standard line.
Maximum differential is desired to be 80″.
A. P. I. gravity of flowing oil = 50°.
Maximum flow = 10,000 gallons per hour.

From Chart B, page 24, Coefficient = 980 gallons per hour.
From Table VII, page 67, Coefficient of $2\frac{1}{8}''\times 6''$ plate = 896.1 gallons per hour.
Coefficient of $2\frac{1}{4}''\times 6''$ plate = 1008 gallons per hour.
Choose the $2\frac{1}{4}''\times 6''$ plate.

COEFFICIENTS

The coefficient, C_M or C_N, in the following formulas, is the quantity which, multiplied by the square root of the gauge reading in inches of water, gives the rate of flow. Liquid coefficients should not be confused with the chart factor used in connection with a direct-reading meter.*

$V = C_M\sqrt{h}$ . . . . *Equation 9*

$W = C_N\sqrt{h}$ . . . . *Equation 10*

V = rate of flow in volume units.
W = rate of flow in weight units.
h = differential in inches of water (see Values of $\sqrt{h}$, Table XIII, page 62.

* Liquid coefficients may be converted to chart factor for flow scale charts by multiplying by $\dfrac{\sqrt{h_m}}{\text{max. chart reading.}}$

$$C_M = \left(\frac{M}{327.2}\right) \times C_W \times F_G \times F_T \quad \ldots\ldots \quad \textit{Equation 25}$$

$$C_N = \left(\frac{N}{327.2}\right) \times C_W \times F_G \times G_f \quad \ldots\ldots \quad \textit{Equation 26}$$

NEW WORKING EQUATIONS FOR PETROLEUM OILS AND WATER

As explained in Section I, more convenient forms of the above equations for petroleum oils and water are obtained by substituting $F_sF_d\sqrt{F_T}$ for F_GF_T and $F_sG_bF_d\sqrt{F_T}$ for F_GG_f.

The working equations, as listed in Section IV, are:

$$C_M = \left(\frac{M}{327.2}\right) C_WF_sF_d\sqrt{F_T} \quad \ldots\ldots \quad \textit{Equation 7}$$

$$C_N = \left(\frac{N}{327.2}\right) C_WF_sG_bF_d\sqrt{F_T} \quad \ldots\ldots \quad \textit{Equation 8}$$

See Section IV for nomenclature, tables, curves, etc.

NEW WORKING EQUATIONS FOR ANY LIQUID WHEN G_f IS KNOWN

The following simplified equations are recommended when G_f, G_s, and G_b are known:

$$C_M = \left(\frac{M}{327.2}\right) C_W \frac{AB}{G_b} \quad \ldots\ldots \quad \textit{Equation 15}$$

$$C_N = \left(\frac{N}{327.2}\right) C_WAB \quad \ldots\ldots \quad \textit{Equation 16}$$

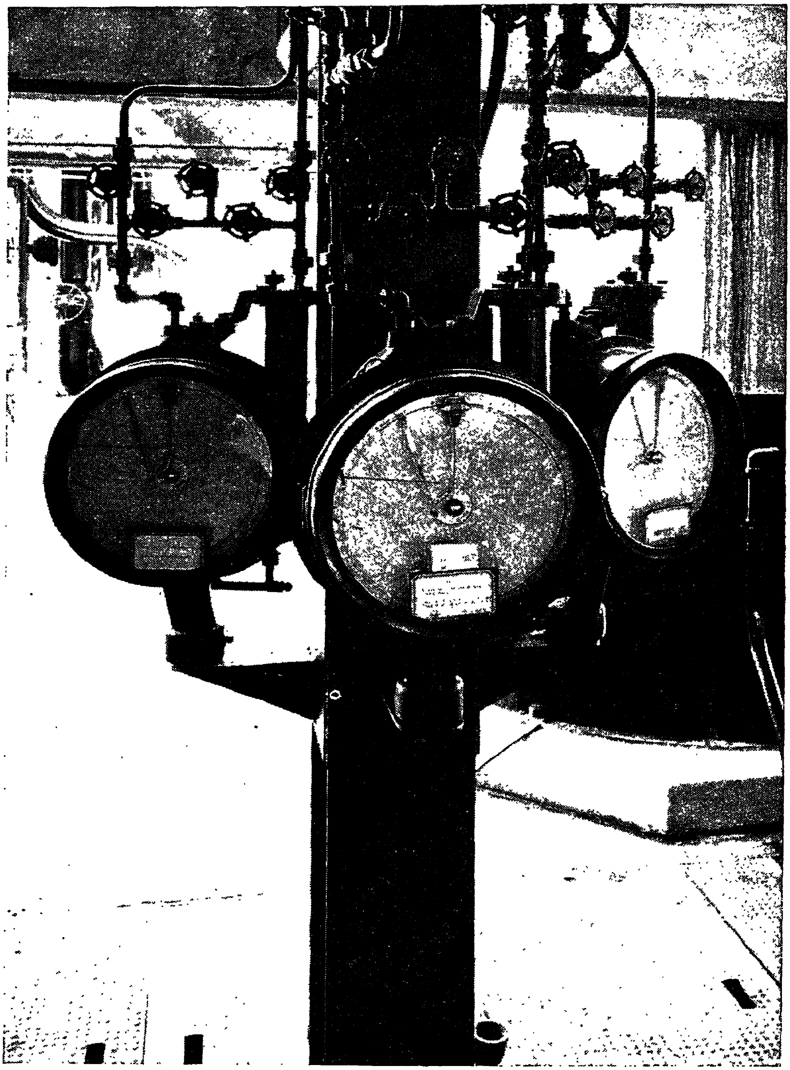


Fig. 8741
Foxboro Flow Meters at Continental Oil Company, Westlake, Louisiana

VENTURI THROATS, FLOW NOZZLES AND PITOT TUBES

Although this book is principally devoted to the discussio of the thin, square, sharp-edged orifice, it would not be complet without some mention of other types of differential-producin devices.

Most flow-meter installations will be made with the thi square, sharp-edged orifice plate. It can be reproduced easil

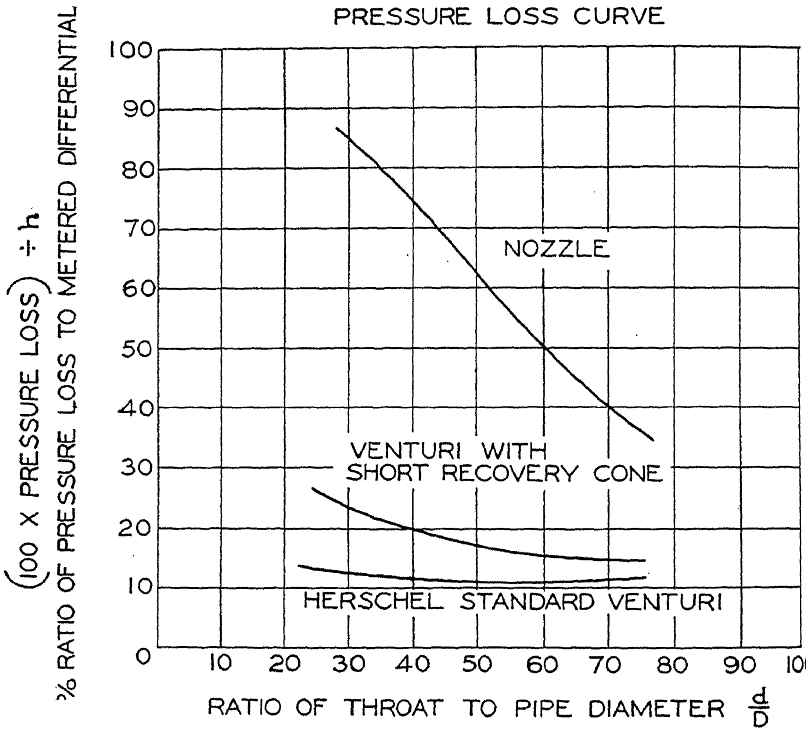


Fig. 4579

Courtesy Builders Iron Foundry. Data by Ed. S. Smith, Jr., M. E., is for smooth finish.

and its coefficients are consistent within close limits on d/D ratios up to .6, and with fair consistency up to .75 d/D ratio. It is easy to install, remove, replace, and easy to clean. It has a great element of flexibility; if one orifice is found too large to give a readable differential under existing conditions, it may be replaced by a plate of smaller bore, and vice versa. It is the cheapest and most convenient means of producing differential in most cases and has the further advantage of high accuracy, provided the velocity is not sufficient to require an excessively high ratio of orifice diameter to line diameter.

The thin, square, sharp-edged orifice has disadvantages which, in some cases, make it preferable to use some other type of primary device. It has the disadvantage that a large part of its pressure drop is permanently lost. The venturi throat is more efficient in this respect and for that reason is preferable where pressure loss is an important consideration.

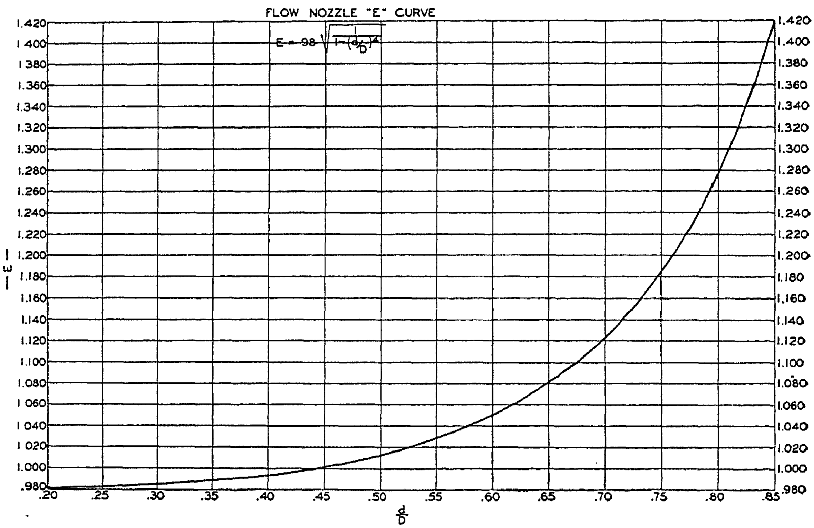


Fig. 4456

The accuracy of the thin, square, sharp-edged orifice is quickly destroyed by deposits of dirt or sediment on the upstream edge. On applications involving the measurement of dirty fluids, the flow nozzle is often preferable to the orifice plate.

However, the principal advantage of the flow nozzle is the fact that its efficiency is so much higher than that of a sharp-

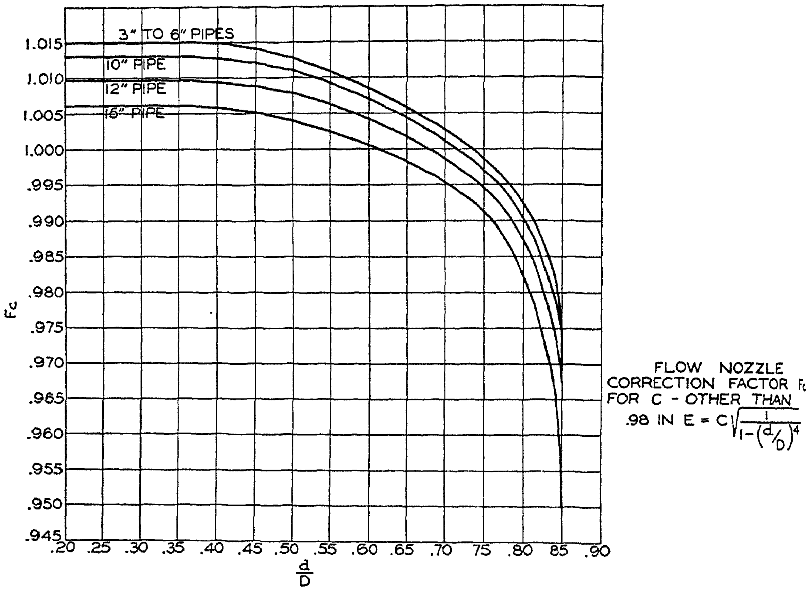


Fig. 4457

edged orifice, that a great deal higher rate of flow may be handled with the same d/D ratio and the same differential.

The Computation of flow through a nozzle or venturi throat is the same as that for the square, sharp-edged orifice, except for the values of E and S. For Foxboro Flow Nozzles, with pressure taps located as recommended by The Foxboro Company, these values are obtained by multiplying values obtained from Fig. 4456 (page 29) and Figs. 4458 (page 31), 4459 (page

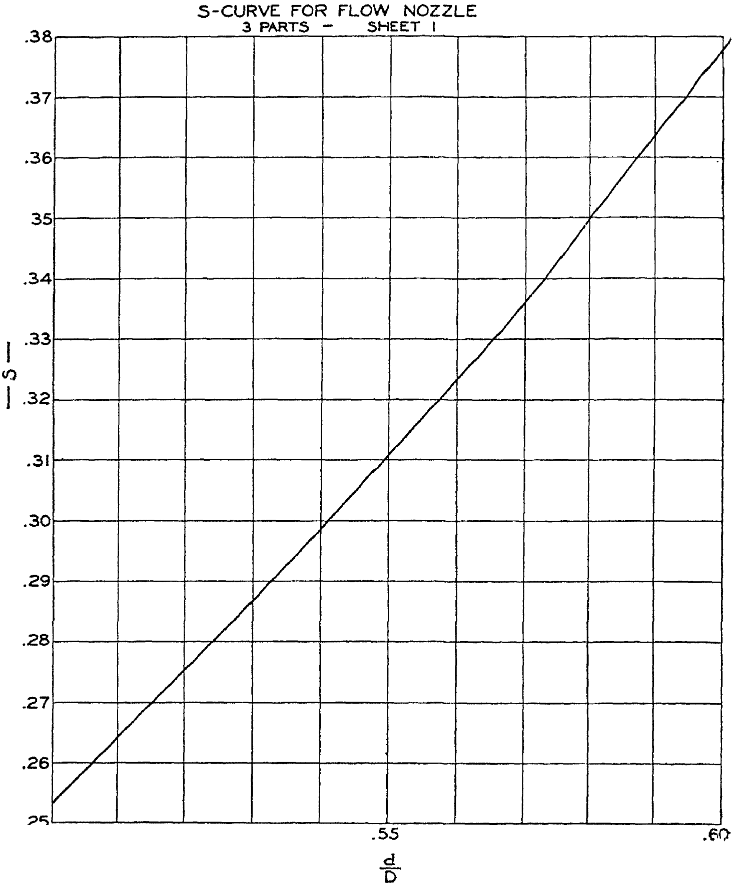


Fig. 4458

32), 4460 (page 33) by values obtained from Fig. 4457 (page 30).

Similar information for computation of venturi throat sizes may be had by writing to The Foxboro Company.

The Foxboro Pitot Tube is useful only under ideal flow conditions. It should not be installed on dirty fluids or in locations

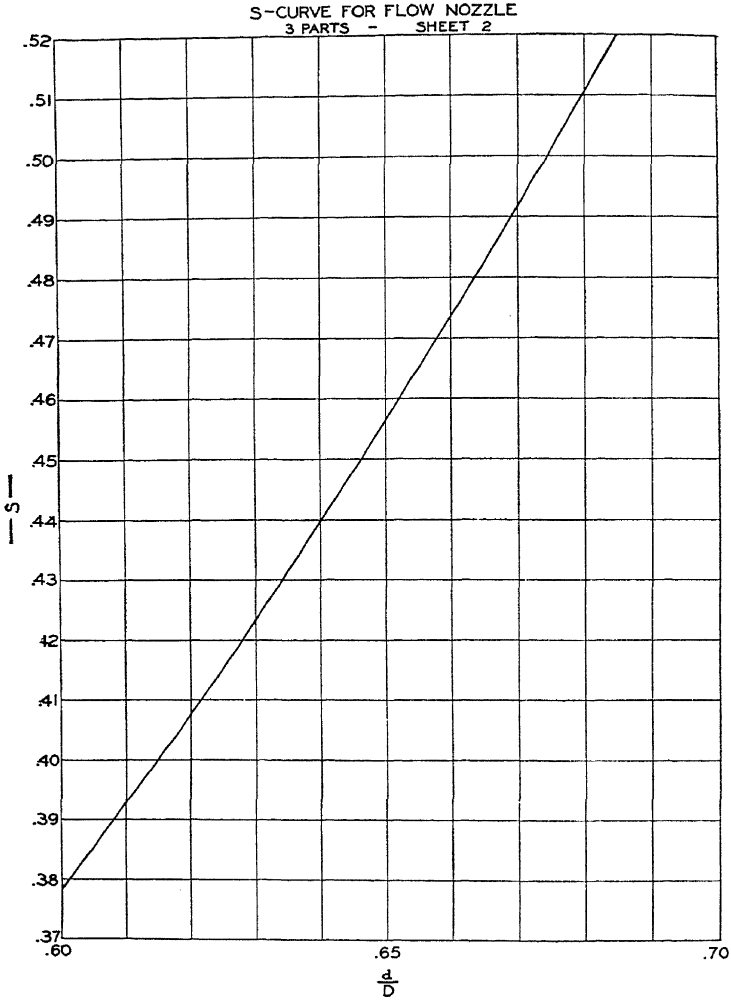


Fig. 4459

where there is any possibility of uneven velocity distribution due to fittings or disturbances ahead of the Pitot Tube.

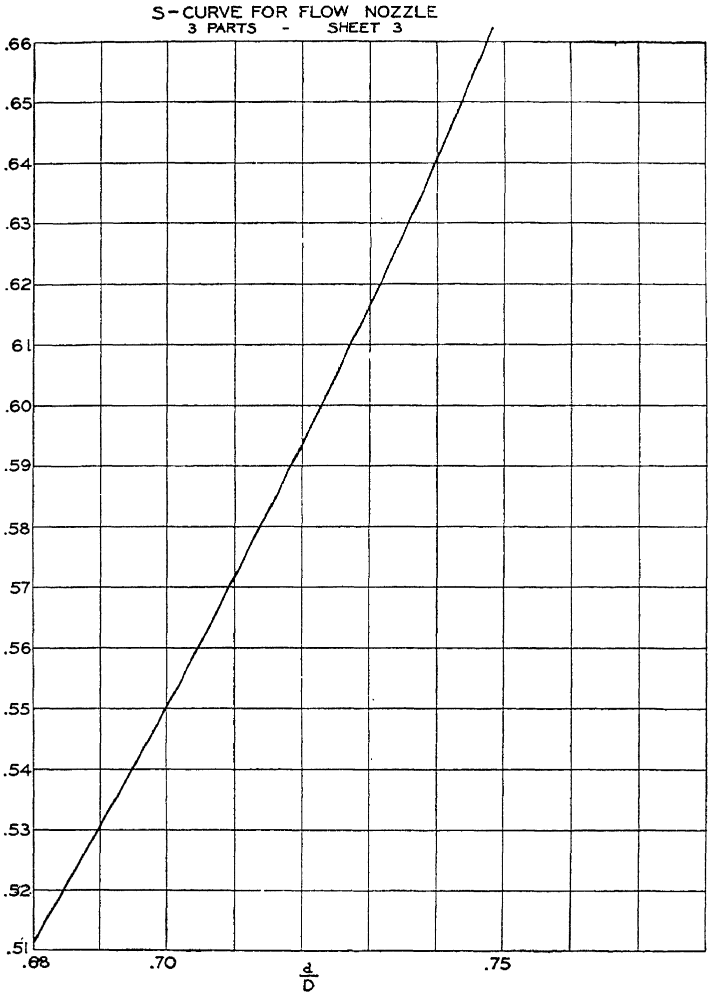


Fig. 4460

The Pitot Tube measures the velocity at the center of the pipe, and the quantity rate of flow is estimated either from an

assumed ratio of average to center velocity or from an experimentally determined traverse of pipe velocities.

Figure 4577 shows the normal ratio of velocities for a smooth iron pipe. Excessive pipe roughness has the effect of decreasing the ratio of average velocity to center velocity.

The pitot tube coefficient is the value C in the formula $v = C\sqrt{2gH}$. It is dependent upon the design and location of the static opening of the tube and to a slight extent upon the design and location of the impact opening. For the Foxboro Pitot Tube this value is .825.

If the value of pitot tube coefficient is multiplied by the ratio of average to maximum velocity, a value of S for the pitot tube is obtained. That is, for the Foxboro Pitot Tube $S = .825 \dfrac{\text{Average velocity}}{\text{Maximum velocity}}$.* Any Foxboro Formula in which the value Ed^2 occurs may be used for pitot tube computations by substituting S for E and line size D for orifice size d. Any Foxboro Flow Formula in which SD^2 occurs may be used for pitot tube calculations without alteration.

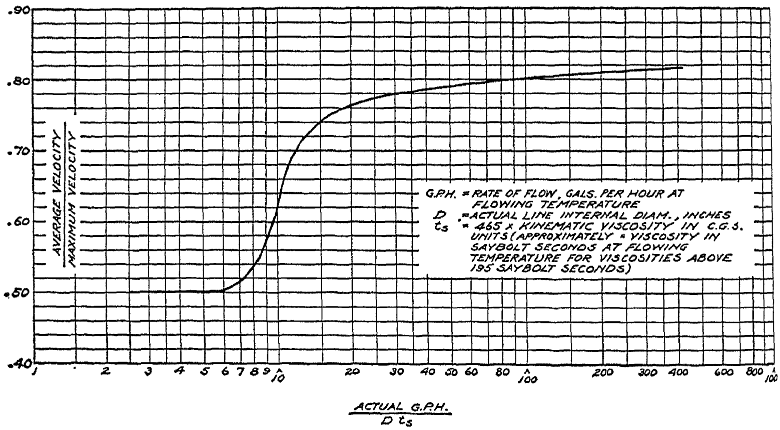


Fig. 4577

* See Figure 4577.

SECTION IIb

CHART COMPUTATION

(For Charts Graduated in Inches of Water Differential)

a. Hourly Method

In computing charts by the hourly method, the average differential for each hour should be written at the edge of the chart. Multipliers corresponding to these differentials may be found in Table XIII, page 62, and should be recorded at the edge of the chart (see Fig. 2806 below). The sum of any number of hourly multipliers times the hourly coefficient equals the flow for that period.

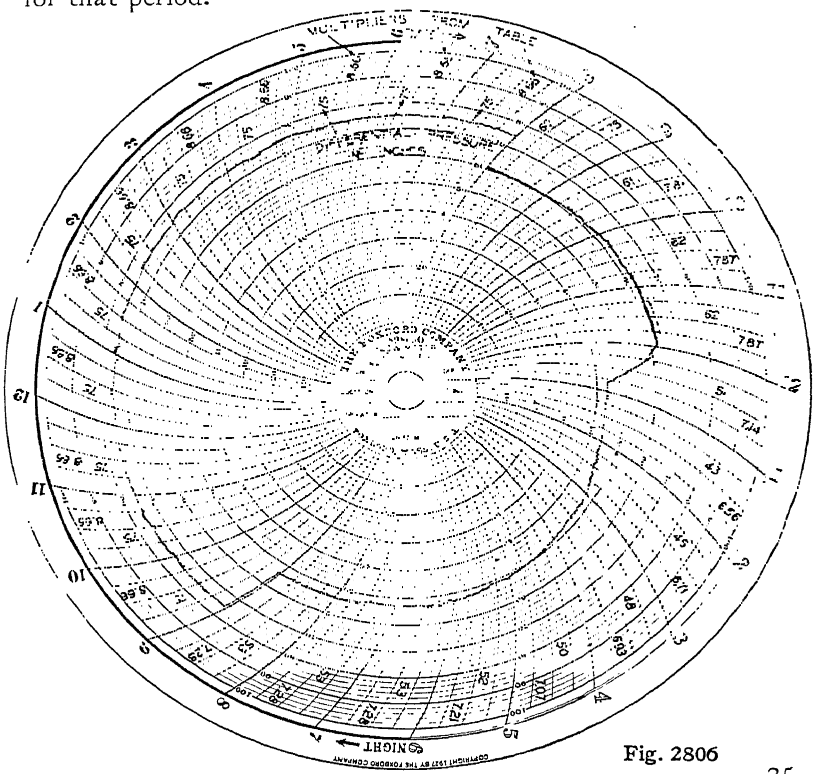


Fig. 2806

b. Planimeter* Method for Differential Scale or Square Root Charts

The 3 D Planimeter shown in Fig. 2808, below, may be used on any Foxboro gas-flow or liquid-flow charts. When instrument is used on liquid-flow charts, Slot G is not utilized. The 3 C Planimeter has only a single curved slot identical with Slot E. It may be used on any Liquid-Flow Meter chart from a Foxboro Type 100 or 500 instrument.

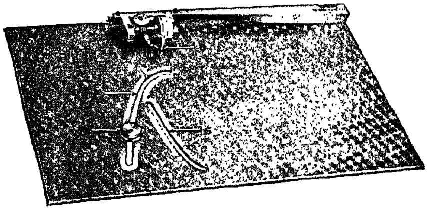


Fig. 2808
FOXBORO SQUARE ROOT PLANIMETER

Operating and Reading Planimeter

Integration is performed in the following manner: Place the center of the chart on Planimeter hub F (Fig. 2808, above) and bring the chart to a position such that the record to be integrated rests under the gooseneck pointer D. Note the registration of the Planimeter; rotate the chart clockwise and again note the registration. Subtract the initial from the final registration and call the resulting Planimeter reading R.

Initial and final registrations of the Planimeter should always be noted at points equidistant from the center of the chart. For example, if the integration is started at 50″ differential and completed at 63″ differential on the 8 a.m. time arc, the chart must be moved so that the pointer follows the 8 a.m. time arc back to 50″ differential and final registration noted at that point. Otherwise, a slight error may be introduced.

* The planimeters must be of the Square Root Type. Polar or radial planimeters will not give an accurate average.

Using Square Root Planimeter for Integrating Liquid-Flow Charts

$$Q = \frac{R\,Q_n}{R_m} \qquad \textit{Equation 27}$$

Q = actual flow in either volume or weight units for period planimetered, whether it be for 24-hour period or any portion of it.

R = planimeter reading.

R_m = instrument reading after integration of outer scale circle for 360° of chart.

Q_m = capacity of meter (obtained from integrator data plate or computed from formula $Q_m = C\sqrt{h_m}$).

C = 24-hour coefficient.

h_m = differential range of instrument (20″, 50″, 60″, or 100″).

Example

(Take data from example on page 74.)

Hourly Coefficient = 1,119 GPH.

$C = 24 \times 1{,}119 = 26{,}860$ gallons per day.

$Q_m = 26{,}860\sqrt{100} = 268{,}600$ gallons per day.

$Q = \frac{268{,}600R}{5}$ gallons/day = 53,720R gallons per day.

Planimeter Reading (R) after integrating flow record = 3.210.

$Q = 3.210 \times 53{,}720$ gallons = 172,400 gallons.

SECTION III

DIRECT-READING METERS

Integrating

The rate of flow may be read direct from either of the types of flow scale charts shown below. Fig. 898074 shows the most com-

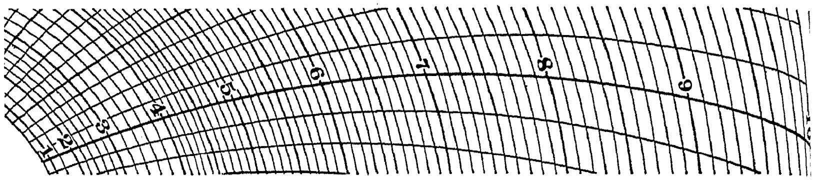


Fig. 898074

monly used square root flow scale chart. Many users standardize on the 0–10 range, using it for all flow ranges with odd multipliers.

Usually it will be found more convenient to use a direct-reading range such that the readings can be converted to rate of flow by merely adding the proper number of ciphers. For instance, on a range of 0–50,000 gallons per hour, we would use a 0–50 chart No. 898130 and multiply all chart readings by 1000 to obtain flow in gallons per hour.

Fig. 838325 shows one of the ranges of flow scale charts used on the uniform flow scale meter.

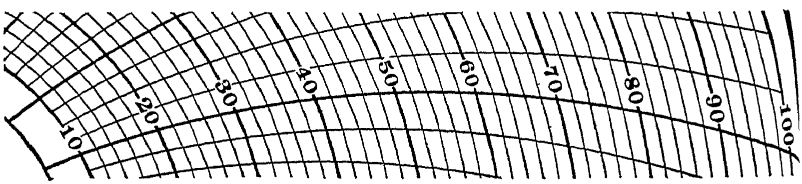


Fig. 838325

The integrator is an automatic totaling device which registers the total number of gallons, barrels, cubic feet, or pounds (units the same as those in which the chart reads) of liquid which flows during the period of time it is operating. Outwardly, the device is similar to the mileage indicator in the speedometer of an automobile, and the flow between any two given times may be obtained by subtracting the earlier reading from the later reading, just as the flow for a given month is obtained from two readings of a domestic gas meter.

Direct-Reading Integrating Meters

The following direct-reading charts are available. Integrators may be used as outlined in Table VIII, if the chart reads in pounds, gallons, barrels, cubic feet, or other units, per *hour*.

Square Root Charts

TABLE VIII — Hourly Flow Ranges

Hourly Flow Range	Chart		Integrator		Chart Multiplier	Integrator Factor
	Number	Range	Code Number	Teeth in Gear A		
0–100	898074	0–10	1101E	40	10	1
0–125	898098	0–125	1102E	50	1	1
0–150	898145	0–15	1103E	6	10	10
0–175	898401	0–17.5	1118E	7	10	10
0–200	898103	0–20	1104E	8	10	10
0–250	898146	0–25	1105E	10	10	10
0–300	898128	0–30	1106E	12	10	10
0–350	898356	0–35	1115E	14	10	10
0–400	898095	0–40	1107E	16	10	10
0–500	898130	0–50	1108E	20	10	10
0–600	898096	0–60	1109E	24	10	10
0–750	898097	0–75	1110E	30	10	10
0–900	898246	0–90	1111E	36	10	10

If the chart reads direct in pounds, gallons, barrels, cubic feet, or other units, per *minute*, integrators can be furnished *only* in the following ranges:

TABLE VIIIa — Minute Flow Ranges

Minute Flow Range	Chart		Integrator		Chart Multiplier	Integrator Factor
	Number	Range	Code Number	Teeth in Gear A		
0–100	898074	0–10	1109E	24	10	100
0–125	898098	0–125	1110E	30	1	100
0–150	898145	0–15	1111E	36	10	100
0–175	898401	0–17.5	1119E	42	10	100
0–200	898103	0–20	1113E	48	10	100
0–250	898146	0–25	1103E	6	10	1000
0–500	898130	0–50	1106E	12	10	1000
0–750	898097	0–75	1112E	18	10	1000

Square Root Charts — *Continued*

If the chart reads direct in pounds, gallons, barrels, cubic feet, or other units, per *day*, integrators can be furnished *only* in the following ranges. The integrating cam used for daily chart ranges is specially calibrated. Therefore, in order to adapt this instrument to *hourly* flow ranges, it is necessary to supply a complete integrating mechanism.

TABLE VIIIb — Daily Flow Ranges

Daily Flow Range	Chart		Integrator		Chart Multiplier	Integrator Factor
	Number	Range	Code Number	Teeth in Gear A		
0–1000	898074	0–10	2107E	16	100	[illegible]
0–1250	898098	0–125	2108E	20	[illegible]	[illegible]
0–1500	898145	0–15	2109E	24	100	[illegible]
0–2000	898103	0–20	2114E	32	100	[illegible]
0–2500	898146	0–25	2101E	40	100	[illegible]
0–3000	898128	0–30	2113E	48	100	[illegible]
0–5000	898130	0–50	2104E	8	100	[illegible]
0–7500	898097	0–75	2106E	12	100	[illegible]

Uniform Flow Scale Charts

TABLE VIIIc — Hourly Flow Ranges

Number	Chart		Integrator	
	Flow Range	Temp. or Pressure Range	Code Number	Teeth in Gear
838325	0–100	0–100	3108E	20
838324	0–100	0–250	3108E	20
838370	0–125	0–125	3116E	25
838360	0–150	0–150	3110E	30
838332	0–200	0–200	3101E	40
838351	0–250	0–250	3102E	50
838346	0–300	0–300	3103E	6
	0–30	0–30	3103E	6
838368	0–40	0–40	3104E	8
838362	0–50	0–50	3105E	10
838361	0–60	0–60	3106E	12
838373	0–75	0–75	3117E	15
	0–90	0–90	3112E	18

COMPUTATION OF ORIFICE SIZE

Integrating or Nonintegrating

To derive an orifice size to be used in a given installation of a direct-reading meter, we must choose a flow limit for the range of the instrument. This maximum capacity must be one of the foregoing ranges or a multiple of ten times one of them.

Having chosen the most suitable range (for instance, suppose the maximum flow will be about 13,500 gal./hr., we would have chosen a range of 15,000 gal./hr., used a chart factor of 1000, and an integrator with a six-tooth Gear A), we now desire to calculate the correct orifice size to use. This is done by use of one of the following equations:

$$S = \frac{v_m}{MD^2\,F_G\,F_T\sqrt{h_m}} \text{ (volume units)} \quad . \quad . \quad . \qquad \textit{Equation 28}$$

$$S = \frac{W_m}{ND^2\,F_G\,G_f\sqrt{h_m}} \text{ (weight units)} \quad . \qquad \textit{Equation 29}$$

S = a function of $\frac{d}{D}$ and may be obtained from the S curve, Fig. 2631, A, B, and C (pages 63, 64, 65).

V_m = flow range wanted if in volume units.

W_m = flow range wanted if in weight units.

M and N are constants given in Table X, page 55.

D^2 = square of actual internal diameter of line. Table XI, page 56.

h_m = differential range of gauge; that is, 100″ (50″ or 20″ may be supplied if necessary).

F_G, G_f, and F_T are correction factors.

These equations give a numerical value for "S." Locate this value on the ordinate of the "S" curve and read the corresponding value of d/D on the abscissa. Multiply this value of d/D by the value of D used in the above equation for "S," and the product is the diameter of the orifice in inches.

New Working Equations for Petroleum Oils and Water

More convenient equations for petroleum oils and water are obtained by substituting $F_s F_d \sqrt{F_T}$ for $F_G F_T$ and substituting $F_s G_b F_d \sqrt{F_T}$ for $F_G G_f$. The working equations become:

$$S = \frac{V_m}{MD^2 F_s F_d \sqrt{F_T}\sqrt{h_m}} \text{ (volume units)} \quad . \; . \; . \quad \textit{Equation 1}$$

$$S = \frac{W_m}{ND^2 F_s G_b F_d \sqrt{F_T}\sqrt{h_m}} \text{ (weight units)} \quad . \; . \; . \quad \textit{Equation 2}$$

New Working Equations for Any Liquid When G_f is Known

The following simplified equations are recommended when G_f, G_s, and G_b are known:

$$S = \frac{V_m G_b}{MD^2 AB\sqrt{h_m}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \textit{Equation 11}$$

$$S = \frac{W_m}{ND^2 AB\sqrt{h_m}} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \textit{Equation 12}$$

See Section IV for nomenclature, tables, curves, etc.

COMPUTATIONS FOR VENA CONTRACTA TAPS

A method of applying flange tap data to measurement by Vena Contracta connected meters by use of a correction factor is presented in the following paragraphs. The ordinate of Fig. 8649 gives values of $F_{vc}=\frac{E_v}{E_f}$, in which E_v is the value of K from Table 7of The American Society of Mechanical Engineers' "Fluid Meters, Their Theory and Application," 1937 Edition. The abscissa of Fig. 8649 is laid out in such a way as to make the data fall on a straight line.

This comparison shows that for most non-viscous flows the liquid calculations for flange taps in Part I of this Handbook may be used with a tolerance of $\pm 2\%$ for meters with vena contracta taps.

If greater accuracy is desired, a correction obtained from Fig. 8649, page 44, should be applied. To do so, the factor F_{vc} is inserted in the numerator of Equation 1 or 2, or in the denominator of Equation 3 or 4 (see page 50). That is, Equation 3 becomes

$$V = \mathbf{MEd^2F_sF_d\sqrt{F_T}F_e\sqrt{h_m}\ F_{vc}} \quad . \quad . \quad . \quad . \quad . \quad . \qquad \textit{Equation 3a}$$

and Equation 1 becomes

$$\mathbf{S} = \frac{\mathbf{V_m}}{\mathbf{MD^2F_sF_d\sqrt{F_T}F_e\sqrt{h_m}\ F_{vc}}} \quad . \quad . \quad . \quad . \quad . \quad . \qquad \textit{Equation 1a}$$

When using Equation 3a, the values of d and d/D are known, permitting F_{vc} to be determined from Fig. 8649.

When using Equation 1a, the values of d and d/D are unknown. Hence, a preliminary calculation must be made to determine the values of d/D and $\frac{\text{G.P.H.*}}{dt_s}$ to use in Fig. 8649. A preliminary calculation of d/D for flange connections may be made on the Foxboro

* See Equation 18, page 51.

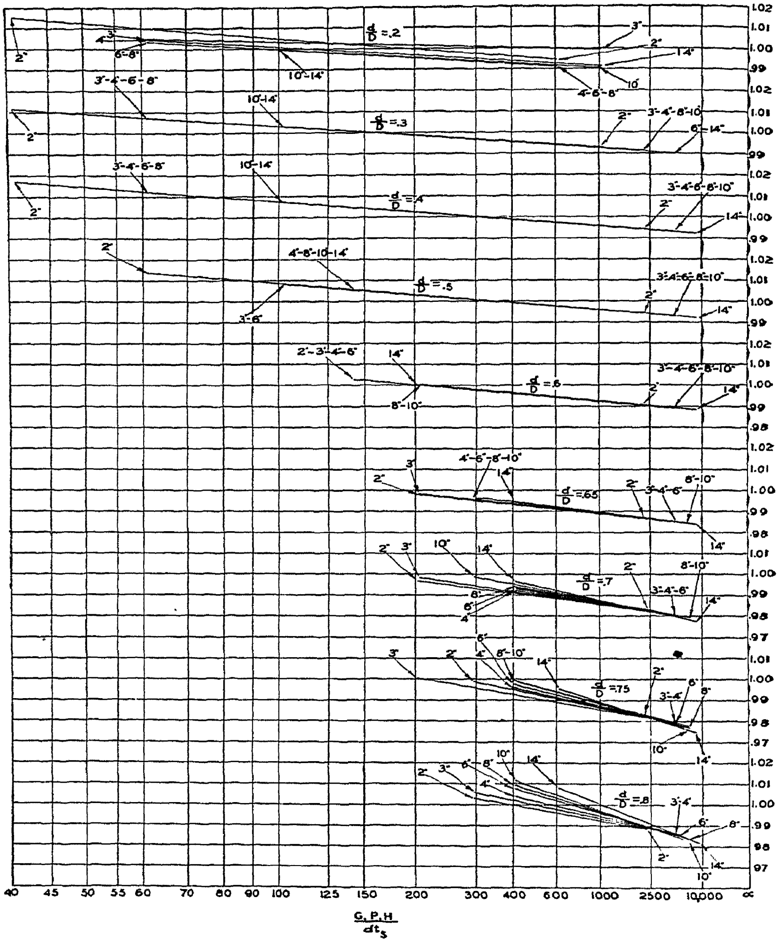


Fig. 8649
CORRECTIONS FOR VENA CONTRACTA TAPS

Orifice Slide Rule or may be performed from Equation 1 assuming $F_{vc} = 1.0$. If, after using the value of F_{vc} obtained from Fig. 8649 to obtain a new d/D by use of Equation 1a, the value were appreciably different from the original, the process should be repeated, using the newly determined d and d/D values on Fig. 8649. Because all of the corrections are small, however, a single determination of F_{vc} should suffice.

Computations for 2½ and 8 Pipe Diameter Connections on Liquids

Since no viscosity data are available for connections at 2½ pipe diameters upstream and 8 pipe diameters downstream from the orifice, it is recommended that the use of these connections be limited to non-viscous flows.

Direct-Reading Orifice Computations for 2½ and 8 Pipe Diameter Taps

Computations for "S" are the same as for flange taps. Ratios of d/D are read from the "S" table for gas, pages 125–135 inclusive.

Coefficients for 2½ and 8 Pipe Diameter Taps

Coefficients from pages 96–97 may be multiplied by .9463 to obtain a liquid coefficient in gallons per hour for 2½ and 8 pipe diameter taps. This product is used as C_W in Equation 7 or 8, page 50.

VISCOSITY

Viscosity effects may safely be neglected *provided* the quantity $\left(\frac{V_h}{dt_s}\right)$ computes more than 332, or the quantity $\left(\frac{W_h}{dt_s G_f}\right)$ computes more than 2770.

In the above formulas

V_h = rate of flow in gallons per hour at flowing temperature.

W_h = rate of flow in pounds per hour

d = diameter of orifice in inches

t_s = 465 × kinematic viscosity in stokes or approximately same as viscosity in Saybolt Universal Seconds at actual flowing temperature for viscosities above 195 seconds. See Table IX, page 49.

G_f = specific gravity of flowing liquid (Water at 60° F. = 1.0).

If these quantities compute less than the specified figures, corrections are necessary.

CORRECTIONS FOR VISCOSITY

Because of the availability of test data on close-up connections, they are recommended for all orifice flow measurements where viscosity effects are indicated. The following data apply to flange or close-up connections.

"Indicated G.P.H." is the rate of flow computed from any of the Equations for non-viscous flow on page 50, *reduced to flowing temperature.* $\frac{\text{Indicated G.P.H.}}{dt_s}$ may be computed from Equation 18. Viscosity correction factor is then read from Fig. 4441.

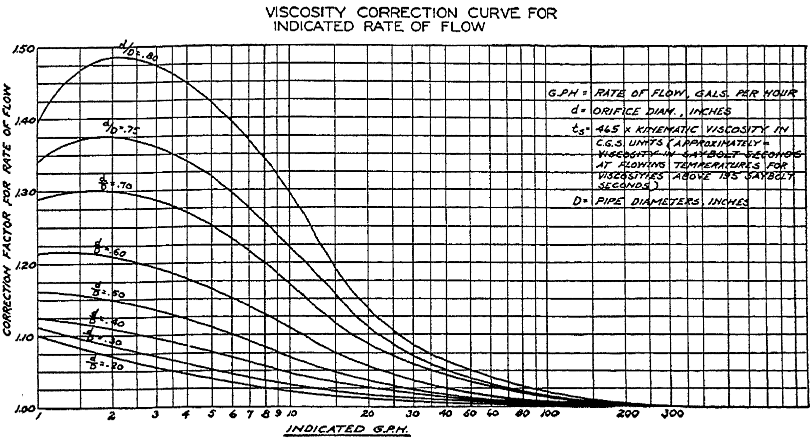


Fig. 4441

Viscous flow data are usually plotted on the basis of actual flow, making it necessary to cut and try to obtain a correction factor for given flow readings on the orifice type meter. The curves shown above, because they are plotted on the basis of a hypothetical flow obtained from the meter readings, will therefore appear "warped" when compared with experimental data. Because of this "warping," however, they may be applied without the usual cut and try procedure. R_d = Reynolds number = $\frac{\text{Indicated G.P.H.}}{dt_s} \times 245.2 \times$ viscosity correction factor.

The value of this correction factor varies with changes in rate of flow. We recommend using it as a multiplier for the flow rate computed from the non-viscous flow formula. If, however, the correction factor is used in the computation of a direct reading orifice, it should be applied in the *denominator* of the equation for "S" and should be based on *normal* flow rate.

Suggestions for Measurement of Viscous Flows

The effect of viscosity is less on the lower values of d/D. Hence, on viscous flows it will be found advantageous to increase the pipe size of the orifice meter run.

In many cases of viscous flow, the venturi tube is preferable to the orifice plate as a primary device because of the more uniform characteristics of the viscosity correction.

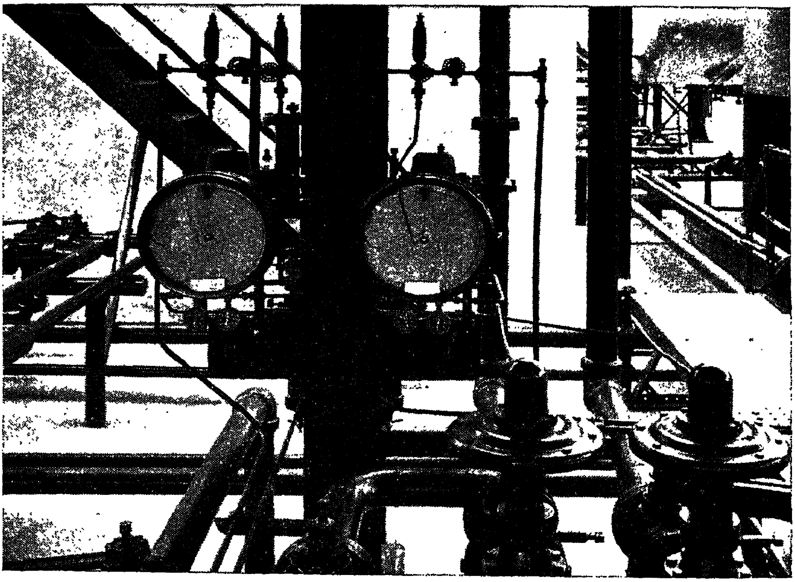


Fig. 8740
Foxboro Flow Controllers at Continental Oil Company, Westlake, Louisiana

TABLE IX
Relation between Saybolt Seconds Universal at Flowing Temperature and t_s

SSU	t_s	SSU	t_s	SSU	t_s	SSU	t_s	SSU	t_s
33	9.7	63	52.0	93	87.8	123	120.4	153	151.9
34	11.0	64	53.4	94	88.9	124	121.5	154	153.0
35	12.3	65	54.6	95	90.0	125	122.5	155	154.0
36	13.8	66	55.9	96	91.1	126	123.6	160	159.1
37	15.3	67	57.1	97	92.2	127	124.6		
38	16.7	68	58.4	98	93.4	128	125.7	165	164.3
39	18.2	69	59.6	99	94.5	129	126.7	170	169.5
40	19.7	70	60.9	100	95.6	130	127.8	175	174.7
41	21.2	71	62.1	101	96.6	131	128.8	180	179.8
42	22.7	72	63.3	102	97.7	132	129.9		
43	24.2	73	64.5	103	98.8	133	130.9	185	184.9
44	25.6	74	65.8	104	99.9	134	132.0	190	190.0
45	27.0	75	67.0	105	101.0	135	133.0		
46	28.5	76	68.1	106	102.1	136	134.1		
47	30.0	77	69.3	107	103.2	137	135.1		
48	31.4	78	70.5	108	104.3	138	136.2		
49	32.9	79	71.6	109	105.4	139	137.2		
50	34.3	80	72.8	110	106.4	140	138.3		
51	35.6	81	74.0	111	107.5	141	139.3		
52	37.0	82	75.1	112	108.6	142	140.4		
53	38.4	83	76.3	113	109.7	143	141.4		
54	39.8	84	77.5	114	110.8	144	142.5		
55	41.1	85	78.6	115	111.9	145	143.6		
56	42.5	86	79.8	116	112.9	146	144.6		
57	43.9	87	81.0	117	114.0	147	145.7		
58	45.3	88	82.1	118	115.1	148	146.7		
59	46.6	89	83.3	119	116.1	149	147.8		
60	48.0	90	84.5	120	117.2	150	148.8		
61	49.3	91	85.6	121	118.3	151	149.9		
62	50.7	92	86.7	122	119.3	152	150.9		

For viscosities above 190, Saybolt Seconds Universal $= t_s$.

When kinematic viscosity is given in C.G.S. units, $t_s = 4.65 \times$ viscosity in centistokes.

When absolute viscosity is given in C.G.S. units, $t_s = \frac{4.65}{G_f} \times$ viscosity in centipoises.

Reduce all viscosities to flowing temperature.

SECTION IV

WORKING SECTION

Thermal Expansion of Primary Devices

Equations in the foregoing sections are based on orifice diameter and pipe diameter at flowing conditions. Since orifice and pipe sizes in commercial practice are measured at atmospheric temperature, it is necessary to introduce a factor in the flow formula for high temperature measurement to correct for expansion of the primary device. Because the bore of the primary device is the predominant factor, the error introduced by assuming that the pipe expands the same as the primary device is negligible. The factor F_e is based on the thermal expansion characteristics of the primary device material, whether applied in equations based on "d" or in those based on "D."

Working Equations

Petroleum Oils or Water

Orifice Size* 1 $$S = \frac{V_m}{MD^2F_sF_d\sqrt{F_T}F_e\sqrt{h_m}}$$

2 $$S = \frac{W_m}{ND^2F_sG_bF_d\sqrt{F_T}F_e\sqrt{h_m}}$$

Rate of Flow 3 $$V = MEd^2F_sF_d\sqrt{F_T}F_e\sqrt{h}$$

4 $$W = NEd^2F_sG_bF_d\sqrt{F_T}F_e\sqrt{h}$$

Rate of Flow 5 $$V = MSD^2F_sF_d\sqrt{F_T}F_e\sqrt{h}$$

6 $$W = NSD^2F_sG_bF_d\sqrt{F_T}F_e\sqrt{h}$$

Coefficient 7 $$C_M = \frac{M}{327.2}C_wF_sF_d\sqrt{F_T}F_e$$

8 $$C_N = \frac{N}{327.2}C_wF_sG_bF_d\sqrt{F_T}F_e$$

Rate of Flow 9 $$V = C_M\sqrt{h}$$

10 $$W = C_N\sqrt{h}$$

Any Liquid When G_f is Known

Orifice Size*	11	$S = \dfrac{V_m G_b}{MD^2F_eAB\sqrt{h_m}}$
	12	$S = \dfrac{W_m}{ND^2F_eAB\sqrt{h_m}}$
Rate of Flow	13	$V = MEd^2F_e\dfrac{AB}{G_b}\sqrt{h}$
	14	$W = NEd^2F_eAB\sqrt{h_m}$
Coefficient	15	$C_M = \dfrac{M}{327.2}C_WF_e\dfrac{AB}{G_b}$
	16	$C_N = \dfrac{N}{327.2}C_WF_eAB$

Miscellaneous Equations

Seal Correction	17	$F_s = \sqrt{\dfrac{1 - .0737G_s}{1 - .0737G_b}}$
Viscosity Operator	18	$\dfrac{\text{Ind. G.P.H.}}{dt_s} = \dfrac{V}{F_Tdt_s} = \dfrac{VG_b}{465d\mu} = \dfrac{R_d}{245.2 \times \text{visc. corr. factor}}$
Thermal Expansion	19	$F_T = \dfrac{G_f}{G_b}$
Cold Gravity Correction	20	$F_d = \sqrt{\dfrac{1 - .0737G_b}{.9263G_b}}$

* Calculate S. Read d/D from S curve. Orifice size = d/D × D.

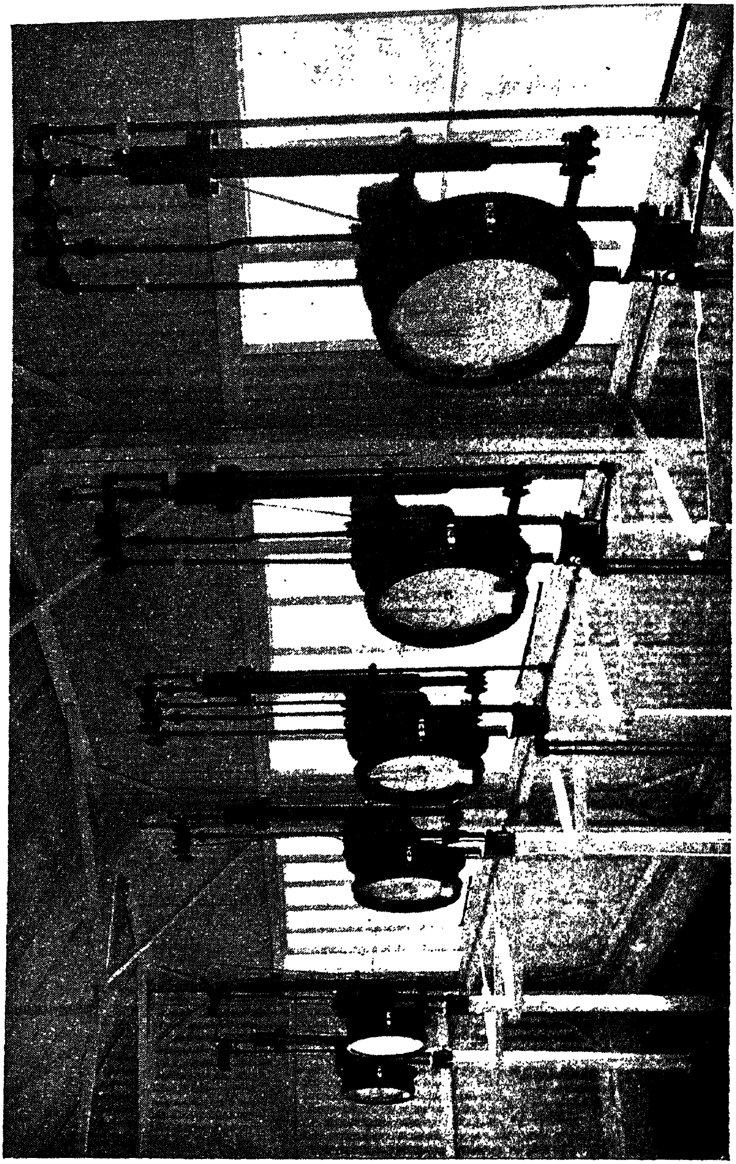


Fig. 8742
Foxboro Flow Meters at Geris Brothers and Jackson Recycling Plant, Grapeland, Texas

NOMENCLATURE

Symbol	Definition	*Units*	Page
M & N	= constants chosen to correspond to units of measurement. See page 55.	Same as V_m or W_m	P. 55
$\frac{M}{327.2}$ & $\frac{N}{327.2}$	= constants used in computing coefficients. See page 55.	Same as V_m or W_m	P. 55
D	= pipe diameter at 60° F. See page 56 for values of D^2	Inches	P. 56
F_s	= correction for seals. $F_s = 1.0$ if no seals are used. See page 57 for values of F_s.		P. 57
$F_d\sqrt{F_T}$	= combined volume correction factor for gravity and temperature. See page 58 for Petroleum Oils, page 61 for Water.		P. 58 and 61
$G_bF_d\sqrt{F_T}$	= combined weight correction factor for gravity and temperature. See page 59 for Petroleum Oils, page 61 for Water.		P. 59 and 61
F_e	= correction for thermal expansion of primary device. See page 60 for values of F_e.		P. 60
h	= operating differential.	Inches of water, dry calibrated	P. 62
h_m	= maximum differential (top of range of instrument). See page 62 for values of $\sqrt{h}$ and $\sqrt{h_m}$.	Inches of water, dry calibrated	P. 62
S	= a value used in determining bore of primary device. See pages 63–65 for flange-connected orifices, pages 125–134 for $2\frac{1}{2}$ and 8 pipe diameter taps, pages 31–33 for flow nozzles or venturi.		P. 63 and 65
E	= efficiency of orifice. See page 66.		P. 66
C_W	= coefficient for measurement of water at 60° F. with water on the surface of the mercury. See page 67.	G.P.H.	P. 67
A	= factor dependent upon G_f. See pages 68 and 69.		P. 68 and 69
B	= factor dependent upon specific gravity of liquid contacting the mercury. See page 70.		P. 70
$\frac{1}{G_b}$	= reciprocal of specific gravity at 60° F. See pages 71 and 72.		P. 71 and 72
C	= coefficients in any units.		
C_M	= volume coefficient, flowing conditions.	Same as M	
C_N	= weight coefficient, flowing conditions.	Same as N	
d	= orifice diameter at 60° F.	Inches	
E_f	= efficiency for flange-connected orifice.		
E_v	= efficiency for vena contracta connected orifice.		
F_d	= density factor for flow at 60° F. See pages 19–21 for values of F_d.		

		Units
F_c	= flow nozzle factor. See page 30.	
F_G	= density factor for flow at flowing temperature.	
F_T	= reciprocal of volumetric temperature expansion ratio. See page 16 for values of $\sqrt{F_T}$.	
F_p	= factor for pressure. See page 18.	
F_{vc}	$= \frac{E_v}{E_f}$, correction for vena contracta taps. See page 44.	
g	= acceleration of gravity.	Ft./sec./sec.
G_b	= specific gravity of the flowing liquid at 60° F. (water at 60° F. = 1.0). See pages 19 – 21 inclusive for values of G_b.	
G_c	= specific gravity at critical temperature and pressure (water at 60° F. = 1.0).	
G_f	= specific gravity of flowing liquid at flowing temperature (water at 60° F. = 1.0).	
G_s	= specific gravity of fluid at surface mercury at the temperature prevailing within mercury chamber (water at 60° F. = 1.0).	
H	= differential pressure in head of flowing liquid.	Feet
h_a	= differential pressure in head of flowing liquid.	Inches
P_R	= reduced pressure = absolute flowing pressure ÷ absolute pseudo-critical pressure.	
R_d	= Reynolds Number based on orifice or throat conditions.	
T_c	= critical temperature. ° F.	
T_R	= reduced temperature = absolute flowing temperature ÷ absolute pseudo-critical temperature.	
	= 4.65 × kinematic viscosity in centistokes or $\frac{4.65}{G_f}$ × absolute viscosity in centipoises.	
Q	= total flow in any specified units in any specified period of time.	
Q_m	= value of Q with pen at maximum differential for a 24-hour period.	
v	= velocity.	Feet per second
V_h	= hourly rate of flow at flowing temperature.	Gallons per hour
W_h	= hourly rate of flow.	Pounds per hour
V	= rate of flow, volume units	Same as M
V_m	= maximum rate of flow (corresponding to maximum scale reading on chart). Volume units. See pages 39 and 40 for chart ranges.	Same as M
W	= rate of flow, weight units.	
W_m	= maximum rate of flow (corresponding to maximum scale reading on chart). Weight units. See pages 39 and 40 for chart ranges.	Same as N
μ	= absolute viscosity.	Poises

Constants for Liquid Flow Measurement

TABLE X

	M					N	
Time	Cu. Ft.	U.S. Gal.	Imp. Gal.	Barrels (42 U.S. Gal.)	Barrels (50 U.S. Gal.)	Pounds	Tons
Second	.01215	.09089	.07568	.002164	.001818	.7578	.0003789
Minute	.7290	5.453	4.541	.1298	.1091	45.47	.02273
Hour	43.74	327.2	272.5	7.790	6.544	2728	1.364
24-Hours	1050	7853	6539	187.0	157.1	65,470	32.74

	$\frac{M}{327.2}$					$\frac{N}{327.2}$	
Time	Cu. Ft.	U.S. Gal.	Imp. Gal.	Barrels (42 U.S. Gal.)	Barrels (50 U.S. Gal.)	Pounds	Tons
Second	.00003713	.0002778	.0002313	.000006614	.000005556	.002316	.000001158
Minute	.002228	.01667	.01388	.0003968	.0003333	.1390	.00006947
Hour	.1337	1.000	.8327	.02381	.02000	8.338	.004169
24-Hours	3.208	24.00	19.98	.5714	.4800	200.1	.1001

TABLE XI

Values of "Squares of Line Diameter"

Nom. Diam.	Sched.	Wt.	D	D^2
1″	40	S	1.049	1.100
	80	XH	.957	.916
	160		.815	.664
		XXH	.599	.359
1¼″	40	S	1.380	1.904
	80	XH	1.278	1.633
	160		1.160	1.346
		XXH	.896	.803
1½″	40	S	1.610	2.592
	80	XH	1.500	2.250
	160		1.338	1.790
		XXH	1.100	1.210
2″	40	S	2.067	4.272
	80	XH	1.939	3.760
	160		1.689	2.853
		XXH	1.503	2.259
2½″	40	S	2.469	6.096
	80	X	2.323	5.396
	160		2.125	4.516
		XXH	1.771	3.136
3″	40	S	3.068	9.413
	80	XH	2.900	8.410
	160		2.626	6.896
		XXH	2.300	5.290
3½″	40	S	3.548	12.59
	80	XH	3.364	11.32
		XXH	2.728	7.442
4″	40	S	4.026	16.21
	80	XH	3.826	14.64
	120		3.626	13.15
	160		3.438	11.82
		XXH	3.152	9.935
5″	40	S	5.047	25.47
	80	XH	4.813	23.17
	120		4.563	20.82
	160		4.313	18.60
		XXH	4.063	16.51
6″	40	S	6.065	36.78
	80	XH	5.761	33.19
	120		5.501	30.26
	160		5.189	26.93
		XXH	4.897	23.98

Nom. Diam.	Sched.	Wt.	D	D^2
8″	30	S	8.071	65.14
	40	S	7.981	63.70
	60		7.813	61.04
	80	XH	7.625	58.14
	100		7.439	55.34
	120		7.189	51.68
	160		6.813	46.42
		XXH	6.875	47.27
10″	30	S	10.136	102.7
	40	S	10.020	100.4
	60	XH	9.75	95.06
	80		9.564	91.47
	100		9.314	86.75
	120		9.064	82.16
	140		8.75	76.56
	160		8.50	72.25
12″		S	12.00	144.0
	30	S	12.09	146.2
	40		11.938	142.5
		XH	11.75	138.1
	60		11.626	135.2
	80		11.376	129.4
	100		11.064	122.4
	120		10.750	115.6
	140		10.500	110.3
	160		10.126	102.5
14″	30	S	13.250	175.6
		XH	13.000	169.0
16″	30	S	15.250	232.6
	40	XH	15.000	225.0
	60		14.688	215.7
	80		14.314	204.9
18″		S	17.182	295.2
	30		17.126	293.3
	40		16.876	284.8
20″		S	19.182	367.9
	30		19.000	361.0
	40		18.814	354.0
	60		18.376	337.7
24″	30		22.876	523.3
	40		22.626	511.9
30″	30		28.750	826.6

S = Standard Weight Pipe XH = Extra Heavy Weight Pipe
XXH = Double Extra Heavy Weight Pipe

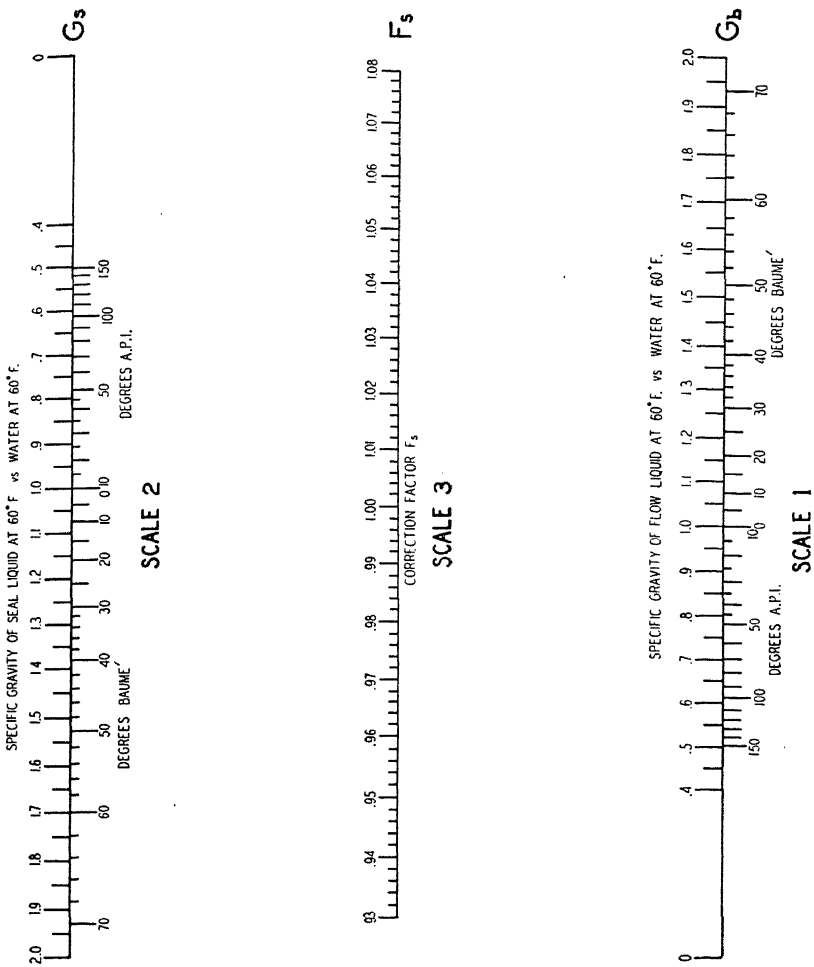


Fig. 8635

CORRECTIONS FOR LIQUID ON MERCURY

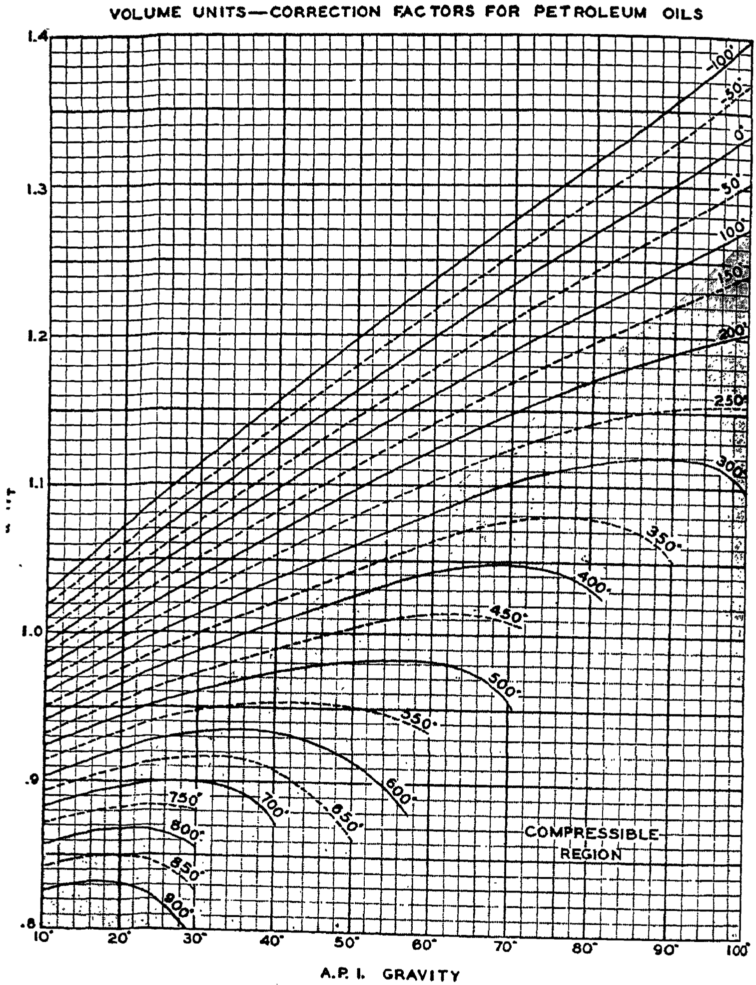


Fig. 8638

Volume Units—Correction Factors For Petroleum Oils

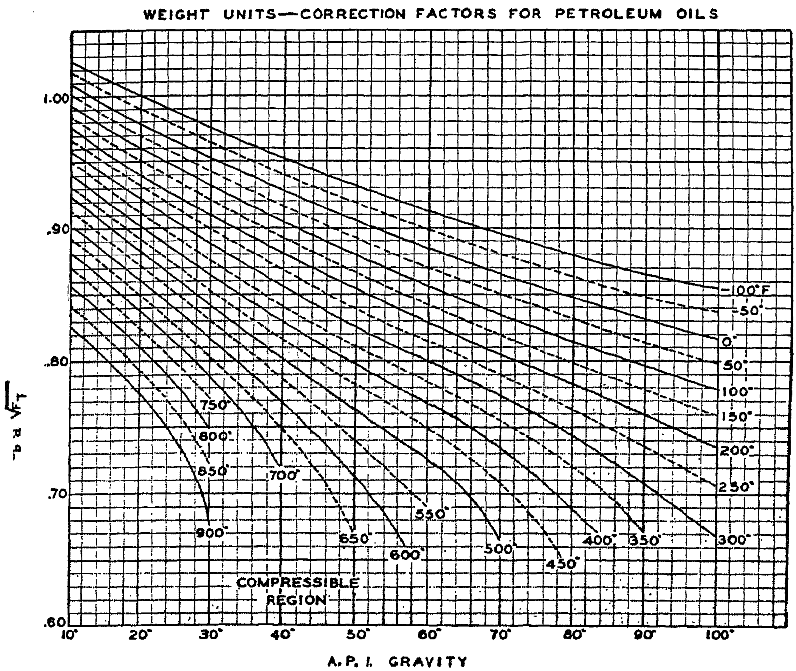


Fig. 8637

Weight Units—Correction Factors For Petroleum Oils

TABLE XII

Values of F_e

Correction for Thermal Expansion of Primary Device

Temp. at Orifice °F.	F_e					
	Steel	Stainless Iron Type 410	Monel Metal	Steam Bronze	KA2S Type 304	KA2SMO Type 316
0	.9992	.9993	.9991	.9988	.9988	.9988
50	.9999	.9999	.9998	.9998	.9998	.9998
60	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
100	1.0005	1.0005	1.0006	1.0008	1.0008	1.0008
150	1.0012	1.0011	1.0014	1.0018	1.0017	1.0017
200	1.0019	1.0017	1.0022	1.0028	1.0027	1.0027
250	1.0025	1.0023	1.0030	1.0038	1.0036	1.0036
300	1.0032	1.0029	1.0037	1.0048	1.0046	1.0046
350	1.0039	1.0035	1.0045	1.0058	1.0055	1.0055
400	1.0045	1.0042	1.0053	1.0068	1.0065	1.0065
450	1.0052	1.0048	1.0061	1.0078	1.0074	1.0074
500	1.0059	1.0054	1.0068	1.0088	1.0084	1.0084
550	1.0065	1.0060	1.0076	.....	1.0093	1.0093
600	1.0072	1.0066	1.0084	.....	1.0103	1.0103
650	1.0079	1.0072	1.0092	.....	1.0112	1.0112
700	1.0085	1.0078	1.0100	.....	1.0122	1.0122
750	1.0092	1.0084	1.0107	.....	1.0132	1.0132
800	1.0099	1.0090	1.0115	.....	1.0141	1.0141
850	1.0105	1.0097	1.0123	.....	1.0151	1.0151
900	1.0112	1.0103	1.0131	.....	1.0160	1.0160
950	1.0119	1.0109	1.0138	.....	1.0170	1.0170
1000	1.0125	1.0115	1.0146	.....	1.0179	1.0179
1050	.....	.....	.....	.....	1.0189	1.0189
1100	.....	.....	.....	.....	1.0198	1.0198
1150	.....	.....	.....	.....	1.0208	1.0208
1200	.....	.....	.....	.....	1.0217	1.0217
1250	.....	.....	.....	.....	.....	1.0227
1300	.....	.....	.....	.....	.....	1.0236
1350	.....	.....	.....	.....	.....	1.0246
1400	.....	.....	.....	.....	.....	1.0255

*This table also indicates maximum temperature at which these materials are used.

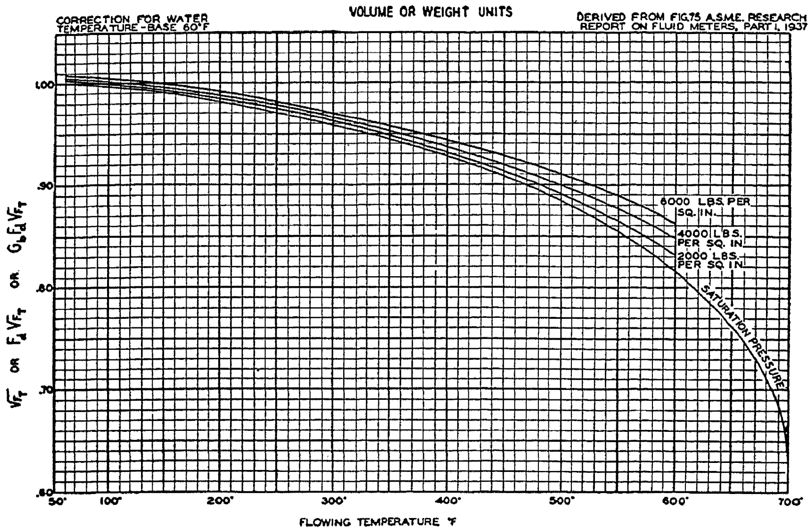


Fig. 8634

Temperature Corrections for Water

TABLE XIII

Differential Pressure Multipliers

1–20 inches of water in tenths inches
20–100 inches of water in inches

h	Mult.	h	Mult.	h	Mult.	h	Mult.	h	Mult.
1.0	1.000	6.5	2.550	12.0	3.464	17.5	4.183	50	7.071
.1	1.049	.6	2.569	.1	3.478	.6	4.195	51	7.141
.2	1.095	.7	2.588	.2	3.492	.7	4.207	52	7.211
.3	1.140	.8	2.608	.3	3.506	.8	4.219	53	7.280
.4	1.183	.9	2.627	.4	3.521	.9	4.231	54	7.348
1.5	1.225	7.0	2.646	12.5	3.535	18.0	4.243	55	7.416
.6	1.265	.1	2.665	.6	3.549	.1	4.255	56	7.483
.7	1.304	.2	2.683	.7	3.563	.2	4.266	57	7.550
.8	1.342	.3	2.702	.8	3.577	.3	4.278	58	7.616
.9	1.378	.4	2.720	.9	3.592	.4	4.289	59	7.681
2.0	1.414	7.5	2.739	13.0	3.606	18.5	4.301	60	7.746
.1	1.449	.6	2.757	.1	3.620	.6	4.313	61	7.810
.2	1.483	.7	2.775	.2	3.633	.7	4.324	62	7.874
.3	1.517	.8	2.793	.3	3.647	.8	4.336	63	7.937
.4	1.549	.9	2.811	.4	3.660	.9	4.347	64	8.000
2.5	1.581	8.0	2.828	13.5	3.674	19.0	4.359	65	8.062
.6	1.612	.1	2.846	.6	3.687	.1	4.370	66	8.124
.7	1.643	.2	2.864	.7	3.701	.2	4.382	67	8.185
.8	1.673	.3	2.881	.8	3.715	.3	4.393	68	8.246
.9	1.703	.4	2.898	.9	3.728	.4	4.404	69	8.307
3.0	1.732	8.5	2.915	14.0	3.742	19.5	4.416	70	8.367
.1	1.761	.6	2.933	.1	3.755	.6	4.427	71	8.426
.2	1.789	.7	2.950	.2	3.768	.7	4.438	72	8.485
.3	1.817	.8	2.966	.3	3.781	.8	4.449	73	8.544
.4	1.844	.9	2.983	.4	3.794	.9	4.461	74	8.602
3.5	1.871	9.0	3.000	14.5	3.808	20.0	4.472	75	8.660
.6	1.897	.1	3.017	.6	3.821	21	4.583	76	8.718
.7	1.924	.2	3.033	.7	3.834	22	4.690	77	8.775
.8	1.949	.3	3.050	.8	3.847	23	4.796	78	8.832
.9	1.975	.4	3.066	.9	3.860	24	4.899	79	8.888
4.0	2.000	9.5	3.082	15.0	3.873	25	5.000	80	8.944
.1	2.025	.6	3.098	.1	3.886	26	5.099	81	9.000
.2	2.049	.7	3.114	.2	3.898	27	5.196	82	9.055
.3	2.074	.8	3.130	.3	3.911	28	5.292	83	9.110
.4	2.098	.9	3.146	.4	3.924	29	5.385	84	9.165
4.5	2.121	10.0	3.162	15.5	3.936	30	5.477	85	9.220
.6	2.145	.1	3.178	.6	3.949	31	5.568	86	9.274
.7	2.168	.2	3.193	.7	3.962	32	5.657	87	9.327
.8	2.191	.3	3.209	.8	3.975	33	5.745	88	9.381
.9	2.214	.4	3.224	.9	3.987	34	5.831	89	9.434
5.0	2.236	10.5	3.240	16.0	4.000	35	5.916	90	9.487
.1	2.258	.6	3.256	.1	4.012	36	6.000	91	9.539
.2	2.280	.7	3.271	.2	4.025	37	6.083	92	9.592
.3	2.302	.8	3.287	.3	4.037	38	6.164	93	9.644
.4	2.324	.9	3.302	.4	4.049	39	6.245	94	9.695
5.5	2.345	11.0	3.317	16.5	4.062	40	6.325	95	9.747
.6	2 366	1	3 331	6	4 074	41	6.403	96	9.798
.7	2.387	.2	3.346	.7	4.086	42	6.481	97	9.849
.8	2.408	.3	3.361	.8	4.098	43	6.557	98	9.899
.9	2.429	.4	3.375	.9	4.111	44	6.633	99	9.950
6.0	2.449	11.5	3.390	17.0	4.123	45	6.708	100	10.000
.1	2.470	.6	3.405	.1	4.135	46	6.782	...	....
.2	2.490	.7	3.419	.2	4.147	47	6.856	...	....
.3	2.510	.8	3.434	.3	4.159	48	6.928	...	....
.4	2.530	.9	3.449	.4	4.171	49	7.000	...	....

FOXBORO S–CURVE
(Flange Connections)

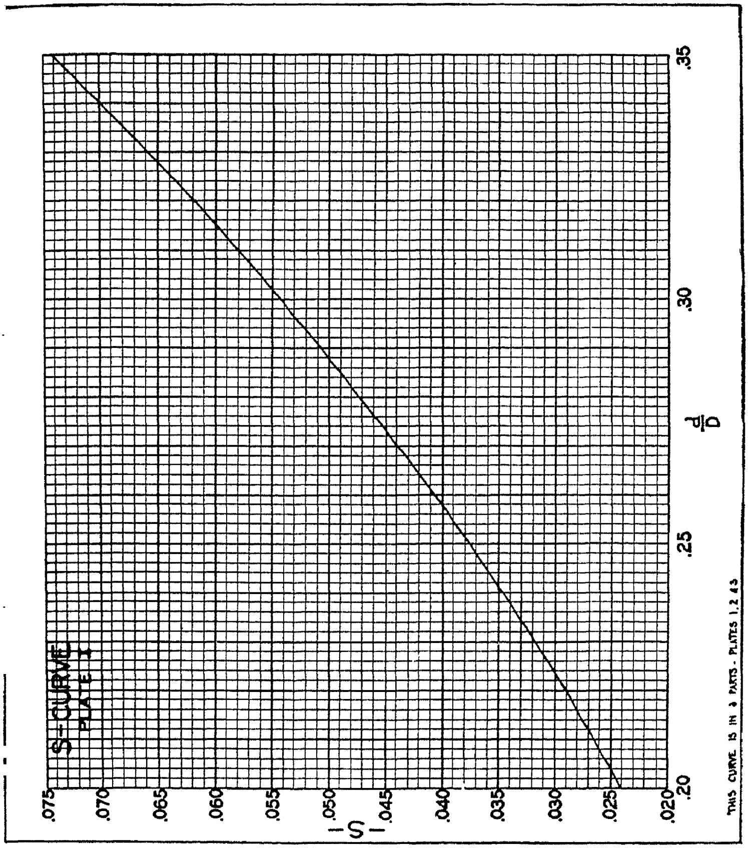
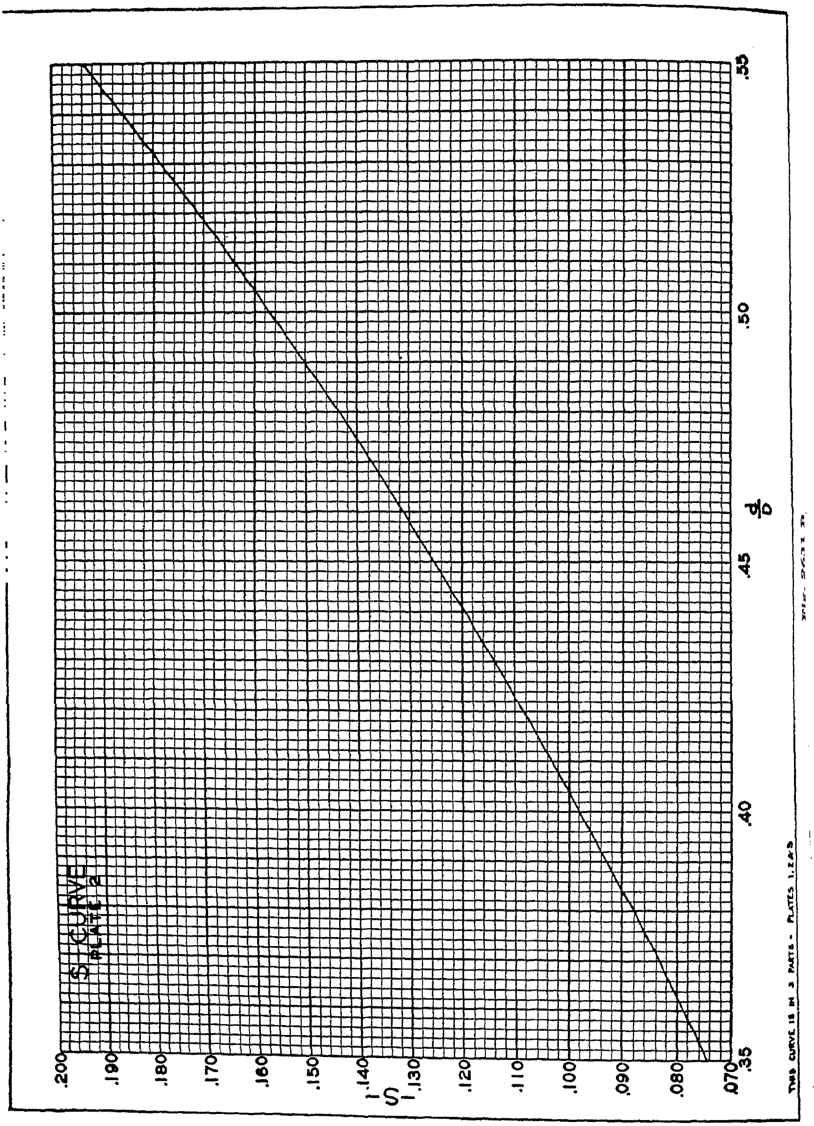


Fig. 2631 A

Continued on pages 64 and 65


S CURVE
PLATE 2
.200
.190
.180
.170
.160
.150
.140
.130
.120
.110
.100
.090
.080
.070
S
.35
.40
.45
.50
.55
d/D
THIS CURVE IS IN 3 PARTS - PLATES 1,2 & 3

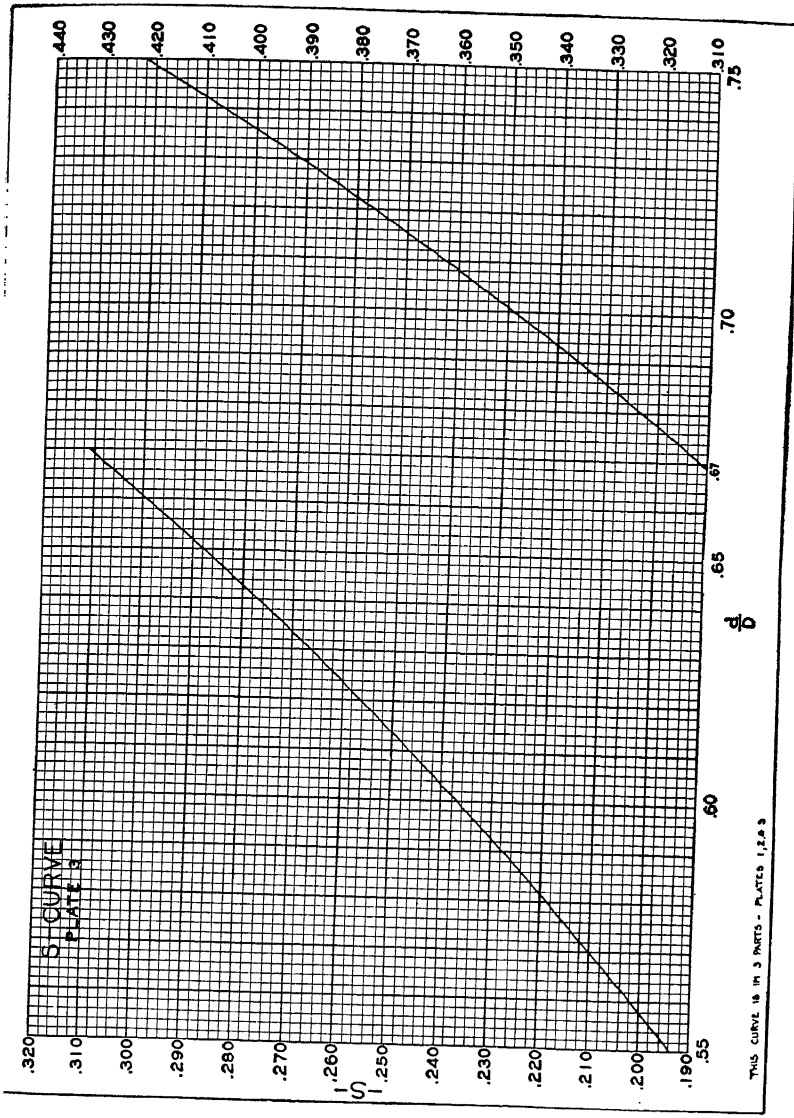

S-CURVE
PLATE 3
THIS CURVE IS IN 3 PARTS - PLATES 1,2 & 3
S-1
d/D
.55
.60
.65
.67
.70
.75
.440
.430
.420
.410
.400
.390
.380
.370
.360
.350
.340
.330
.320
.310
.320
.310
.300
.290
.280
.270
.260
.250
.240
.230
.220
.210
.200
.190

Fig. 2631 C.

TABLE XIV

Values of E for Flange Connections (Liquids)					
d/D	E	d/D	E	d/D	E
.05	.5985	.30	.6035	.55	.6403
.06	.5986	.31	.6040	.56	.6434
.07	.5987	.32	.6045	.57	.6468
.08	.5988	.33	.6051	.58	.6503
.09	.5989	.34	.6058	.59	.6541
.10	.5990	.35	.6065	.60	.6580
.11	.5991	.36	.6072	.61	.6622
.12	.5992	.37	.6081	.62	.6667
.13	.5994	.38	.6090	.63	.6714
.14	.5995	.39	.6099	.64	.6763
.15	.5996	.40	.6110	.65	.6815
.16	.5998	.41	.6121	.66	.6869
.17	.5999	.42	.6133	.67	.6928
.18	.6001	.43	.6147	.68	.6988
.19	.6002	.44	.6161	.69	.7052
.20	.6004	.45	.6176	.70	.7119
.21	.6006	.46	.6193	.71	.7189
.22	.6008	.47	.6210	.72	.7263
.23	.6010	.48	.6229	.73	.7340
.24	.6013	.49	.6250	.74	.7421
.25	.6016	.50	.6271	.75	.7505
.26	.6019	.51	.6294	.76	.7594
.27	.6023	.52	.6319	.77	.7687
.28	.6027	.53	.6345	.78	.7783
.29	.6031	.54	.6373	.79	.7884

Values calculated from empirical formula

$$E = .598 + .01\frac{d}{D} + .00001947\left(\frac{10d}{D}\right)^{4.425}$$

TABLE VII
C_W
For Flange Connections
Coefficients for Water in Gallons Per Hour at 60° F. (15.56° C.)
Water on Surface of Mercury

$M = 327.2 \quad F_G = 1.0$

Orifice	C_W for 2.067″ Line	C_W for 3.068″ Line	C_W for 4.026″ Line	C_W for 6.065″ Line	C_W for 8.071″ Line
.125	3.060	3.059	3.059	3.058	3.058
.250	12.25	12.25	12.24	12.24	12.24
.375	27.61	27.57	27.56	27.54	27.54
.500	49.19	49.06	49.00	48.98	48.97
.625	77.14	76.74	76.64	76.56	76.53
.750	111.8	110.7	110.5	110.3	110.2
.875	153.8	151.0	150.5	150.2	150.1
1.000	204.1	197.9	196.8	196.3	196.1
.125	264.5	251.8	249.6	248.5	248.2
.250	337.3	312.7	308.7	307.0	306.6
.375	426.9	382.0	374.9	371.8	371.1
.500	537.9	460.0	447.8	442.9	441.8
.625	<u>677.9</u>	548.4	528.3	520.3	518.8
.750	.....	648.5	616.6	604.2	602.0
.875	.....	758.1	713.6	694.7	691.5
2.000	.....	894.1	819.9	792.0	787.3
.125	.....	1046.	936.6	896.1	889.5
.250	.....	1209.	1065.	1008.	998.2
.375	.....	<u>1428.</u>	1207.	1126.	1113.
.500	.....	......	1364	1252.	1235.
.625	.....	......	1541.	1387.	1364.
.750	.....	......	1734.	1530.	1499.
.875	.....	......	1952.	1682.	1641.
3.000	.....	......	2198.	1843.	1791.
.125	.....	......	<u>2475.</u>	2015.	1948.
.250	.....	......	......	2198.	2113.
.375	.....	......	......	2394.	2285.
.500	.....	......	......	2602.	2466.
.625	.....	......	......	2825.	2655.
.750	.....	......	......	3064.	2853.
.875	.....	......	......	3320.	3061.
4.000	.....	......	......	3595.	3278.
.250	.....	......	......	4210.	3745.
.500	.....	......	......	4928.	4258.
.750	.....	......	......	<u>5770.</u>	4824.
5.000	.....	......	......	......	5452.
.250	.....	......	......	......	6148.
.500	.....	......	......	......	6926.
.750	.....	......	......	......	7796.
6.000	.....	......	......	......	8775.

Note: Coefficients for orifices whose diameters are high ratios to pipe diameters are underlined. These should not be used when accurate results are desired.

TABLE XV

Values of A

Gr	0	2	4	6	8
.40	.632	.634	.636	.637	.639
.41	.640	.642	.643	.645	.647
.42	.648	.650	.651	.653	.654
.43	.656	.657	.659	.660	.662
.44	.663	.665	.666	.668	.669
.45	.671	.672	.674	.675	.677
.46	.678	.680	.681	.683	.684
.47	.686	.687	.688	.690	.691
.48	.693	.694	.696	.697	.699
.49	.700	.701	.703	.704	.706
.50	.707	.709	.710	.711	.713
.51	.714	.716	.717	.718	.720
.52	.721	.722	.724	.725	.727
.53	.728	.729	.731	.732	.733
.54	.735	.736	.738	.739	.740
.55	.742	.743	.744	.746	.747
.56	.748	.750	.751	.752	.754
.57	.755	.756	.758	759	.760
.58	.762	.763	.764	.766	.767
.59	.768	.769	.771	.772	.773
.60	.775	.776	.777	.778	.780
.61	.781	.782	.784	.785	.786
.62	.787	.789	.790	.791	.792
.63	.794	.795	.796	.797	.799
.64	.800	.801	802	.804	.805
.65	.806	.807	.809	.810	.811
.66	.812	.814	.815	.816	817
.67	.819	.820	.821	.822	.823
.68	.825	.826	.827	.828	.829
.69	.831	.832	.833	.834	.835
.70	.837	.838	.839	.840	.841
.71	.843	.844	.845	.846	.847
.72	.849	.850	.851	.852	.853
.73	.854	.856	.857	.858	.859
.74	.860	.861	.863	.864	.865

Continued on page 69

TABLE XV — *Continued*

Values of A

G_f	0	2	4	6	8
.75	.866	.867	.868	.869	.871
.76	.872	.873	.874	.875	.876
.77	.877	.879	.880	.881	.882
.78	.883	.884	.885	.887	.888
.79	.889	.890	.891	.892	.893
.80	.894	.896	.897	.898	.899
.81	.900	.901	.902	.903	.904
.82	.906	.907	.908	.909	.910
.83	.911	.912	.913	.914	.915
.84	.917	.918	.919	.920	.921
.85	.922	.923	.924	.925	.926
.86	.927	.928	.930	.931	.932
.87	.933	.934	.935	.936	.937
.88	.938	.939	.940	.941	.942
.89	.943	.944	.946	.947	.948
.90	.949	.950	.951	.952	.953
.91	.954	.955	.956	.957	.958
.92	.959	.960	.961	.962	.963
.93	.964	.965	.966	.967	.969
.94	.970	.971	.972	.973	.974
.95	.975	.976	.977	.978	.979
.96	.980	.981	.982	.983	.984
.97	.985	.986	.987	.988	.989
.98	.990	.991	.992	.993	.994
.99	.995	.996	.997	.998	.999
1.0	1.000	1.010	1.020	1.030	1.039
1.1	1.049	1.058	1.068	1.077	1.086
1.2	1.095	1.105	1.114	1.122	1.131
1.3	1.140	1.149	1.158	1.166	1.175
1.4	1.183	1.192	1.200	1.208	1.217
1.5	1.225	1.233	1.241	1.249	1.257
1.6	1.265	1.273	1.281	1.288	1.296
1.7	1.304	1.311	1.319	1.327	1.334
1.8	1.342	1.349	1.356	1.364	1.371
1.9	1.378	1.386	1.393	1.400	1.407

TABLE XVI

Values of B

G_s or G_b	0	2	4	6	8
.0	1.039	.....	.....	.....	.....
.4	1.024	1.023	1.022	1.021	1.020
.5	1.020	1.019	1.018	1.017	1.017
.6	1.016	1.015	1.014	1.013	1.013
.7	1.012	1.011	1.010	1.010	1.009
.8	1.008	1.007	1.006	1.006	1.005
.9	1.004	1.003	1.002	1.002	1.001
1.0	1.000	.999	.998	.998	.997
1.1	.996	.995	.994	.994	.993
1.2	.992	.991	.990	.990	.989
1.3	.988	.987	.986	.986	.985
1.4	.984	.983	.982	.982	.981
1.5	.980	.979	.978	.977	.977
1.6	.976	.975	.974	.973	.973
1.7	.972	.971	.970	.969	.968
1.8	.968	.967	.966	.965	.964

TABLE XVII

Values of $\frac{1}{G_b}$

G_b	0	1	2	3	4	5	6	7	8	9
.40	2.500	2.494	2.488	2.481	2.475	2.469	2.463	2.457	2.451	2.445
.41	2.439	2.433	2.427	2.421	2.415	2.410	2.404	2.398	2.392	2.387
.42	2.381	2.375	2.370	2.364	2.358	2.353	2.347	2.342	2.336	2.331
.43	2.326	2.320	2.315	2.309	2.304	2.299	2.294	2.288	2.283	2.278
.44	2.273	2.268	2.262	2.257	2.252	2.247	2.242	2.237	2.232	2.227
.45	2.222	2.217	2.212	2.208	2.203	2.198	2.193	2.188	2.183	2.179
.46	2.174	2.169	2.165	2.160	2.155	2.151	2.146	2.141	2.137	2.132
.47	2.128	2.123	2.119	2.114	2.110	2.105	2.101	2.096	2.092	2.088
.48	2.083	2.079	2.075	2.070	2.066	2.062	2.058	2.053	2.049	2.045
.49	2.041	2.037	2.033	2.028	2.024	2.020	2.016	2.012	2.008	2.004
.50	2.000	1.996	1.992	1.988	1.984	1.980	1.976	1.972	1.969	1.965
.51	1.961	1.957	1.953	1.949	1.946	1.942	1.938	1.934	1.931	1.927
.52	1.923	1.919	1.916	1.912	1.908	1.905	1.901	1.898	1.894	1.890
.53	1.887	1.883	1.880	1.876	1.873	1.869	1.866	1.862	1.859	1.855
.54	1.852	1.848	1.845	1.842	1.838	1.835	1.832	1.828	1.825	1.821
.55	1.818	1.815	1.812	1.808	1.805	1.802	1.799	1.795	1.792	1.789
.56	1.786	1.783	1.779	1.776	1 773	1.770	1.767	1.764	1.761	1.757
.57	1.754	1.751	1.748	1.745	1.742	1.739	1.736	1.733	1.730	1.727
.58	1.724	1.721	1.718	1.715	1.712	1.709	1.706	1.704	1.701	1.698
.59	1.695	1.692	1.689	1.686	1.684	1.681	1.678	1.675	1.672	1.669
.60	1.667	1.664	1.661	1.658	1.656	1.653	1.650	1.647	1.645	1.642
.61	1.639	1.637	1.634	1.631	1.629	1.626	1.623	1.621	1.618	1.616
.62	1.613	1.610	1.608	1.605	1.603	1.600	1.597	1.595	1.592	1.590
.63	1.587	1.585	1.582	1.580	1.577	1.575	1.572	1.570	1.567	1.565
.64	1.563	1.560	1.558	1.555	1.553	1.550	1.548	1.546	1.543	1.541
.65	1.538	1.536	1.534	1.531	1.529	1.527	1.524	1.522	1.520	1.517
.66	1.515	1.513	1.511	1.508	1.506	1.504	1.502	1.499	1.497	1.495
.67	1.493	1.490	1.488	1.486	1.484	1.481	1.479	1.477	1.475	1.473
.68	1.471	1.468	1.466	1.464	1.462	1.460	1.458	1.456	1.453	1.451
.69	1.449	1.447	1.445	1.443	1.441	1.439	1.437	1.435	1.433	1.431
.70	1.429	1.427	1.425	1.422	1.420	1.418	1.416	1.414	1.412	1.410
.71	1.408	1.406	1.404	1.403	1.401	1.399	1.397	1.395	1.393	1.391
.72	1.389	1.387	1.385	1.383	1.381	1.379	1.377	1.376	1.374	1.372
.73	1.370	1.368	1.366	1.364	1.362	1.361	1.359	1.357	1.355	1.353
.74	1.351	1.350	1.348	1.346	1.344	1.342	1.340	1.339	1.337	1.335

Continued on page 72

TABLE XVII — *Continued*

VALUES OF $\frac{1}{G_b}$

G_b	0	1	2	3	4	5	6	7	8	9
.75	1.333	1.332	1.330	1.328	1.326	1.325	1.323	1.321	1.319	1.318
.76	1.316	1.314	1.312	1.311	1.309	1.307	1.305	1.304	1.302	1.300
.77	1.299	1.297	1.295	1.294	1.292	1.290	1.289	1.287	1.285	1.284
.78	1.282	1.280	1.279	1.277	1.276	1.274	1.272	1.271	1.269	1.267
.79	1.266	1.264	1.263	1.261	1.259	1.258	1.256	1.255	1.253	1.252
.80	1.250	1.248	1.247	1.245	1.244	1.242	1.241	1.239	1.238	1.236
.81	1.235	1.233	1.232	1.230	1.229	1.227	1.225	1.224	1.222	1.221
.82	1.220	1.218	1.217	1.215	1.214	1.212	1.211	1.209	1.208	1.206
.83	1.205	1.203	1.202	1.200	1.199	1.198	1.196	1.195	1.193	1.192
.84	1.190	1.189	1.188	1.186	1.185	1.183	1.182	1.181	1.179	1.178
.85	1.176	1.175	1.174	1.172	1.171	1.170	1.168	1.167	1.166	1.164
.86	1.163	1.161	1.160	1.159	1.157	1.156	1.155	1.153	1.152	1.151
.87	1.149	1.148	1.147	1.145	1.144	1.143	1.142	1.140	1.139	1.138
.88	1.136	1.135	1.134	1.133	1.131	1.130	1.129	1.127	1.126	1.125
.89	1.124	1.122	1.121	1.120	1.119	1.117	1.116	1.115	1.114	1.112
.90	1.111	1.110	1.109	1.107	1.106	1.105	1.104	1.103	1.101	1.100
.91	1.099	1.098	1.096	1.095	1.094	1.093	1.092	1.091	1.089	1.088
.92	1.087	1 086	1.085	1.083	1.082	1.081	1.080	1.079	1.078	1.076
.93	1.075	1.074	1.073	1.072	1.071	1.070	1.068	1.067	1.066	1.065
.94	1.064	1.063	1.062	1.060	1.059	1.058	1.057	1.056	1.055	1.054
.95	1.053	1.052	1.050	1.049	1.048	1.047	1.046	1.045	1.044	1.043
.96	1.042	1.041	1.040	1.038	1.037	1.036	1.035	1.034	1.033	1.032
.97	1.031	1.030	1.029	1.028	1.027	1.026	1.025	1.024	1.022	1.021
.98	1.020	1.019	1.018	1.017	1.016	1.015	1.014	1.013	1.012	1.011
.99	1.010	1.009	1.008	1.007	1.006	1.005	1.004	1.003	1.002	1.001
1.0	1.000	.990	.980	.971	.962	.952	.943	.935	.926	.917
1.1	.909	.901	.893	.885	.877	.870	.862	.855	.847	.840
1.2	.833	.826	.820	.813	.806	.800	.794	.787	.781	.775
1.3	.769	.763	.758	.752	.746	.741	.735	.730	.725	.719
1.4	.714	.709	.704	.699	.694	.690	.685	.680	.676	.671
1.5	.667	.662	.658	.654	.649	.645	.641	.637	.633	.629
1.6	.625	.621	.617	.613	.610	.606	.602	.599	.595	.592
1.7	.588	.585	.581	.578	.575	.571	.568	.565	.562	.559
1.8	.556	.552	.549	.546	.543	.541	.538	.535	.532	.529
1.9	.526	.524	.521	.518	.515	.513	.510	.508	.505	.502

ILLUSTRATING MEASUREMENT OF RESIDUUM WITH KEROSENE PURGE

Flow	50 G.P.M. Max. Use Chart 898130, range 0–50
Pipe Size	2″ Schedule 40, 2.067″ I.D.
Flowing Fluid	Residuum, 10° A.P.I.
Fluid on Mercury . . .	Oil purge, 40° A.P.I.
Flowing Temperature .	400° F.
Orifice Plate Material .	Steel
Differential Range . . .	50″ Water, dry calibration
Tap Location	Flange
Viscosity	Negligible at flowing temperature

Pseudo-Critical Temperature = 1040° F.

Problem	Calculate orifice size for direct-reading meter

Calculation

Use Equation 1, Page 50

V_m	= 50 G.P.M.	
M	= 5.453	Page 55
D^2	= 4.272	Page 56
F_s	= 1.007	Page 57
F_d	= 1.0	Page 19
$\sqrt{F_T}$	= .924	Page 16
F_e	= 1.0045	Page 60
$\sqrt{h_m}$	= 7.071	Page 62

$$S = \frac{50}{5.453 \times 4.272 \times 1.007 \times .924 \times 1.0045 \times 7.071} = .3248$$

d/D = .6814, Page 65; d = .6814 × 2.067″ = 1.408″

ILLUSTRATING COEFFICIENT CALCULATION

Maximum Flow	10,000 G.P.H.
Pipe Size	6″ Schedule 40, 6.065″ I.D.
Flowing Fluid	Oil, 50° A.P.I.
Fluid on Mercury	Oil, 50° A.P.I.
Flowing Temperature . .	163° F.
Orifice Material	Steel
Differential Range	100″ Water, dry calibration
Tap Location	Flange
Viscosity	Negligible
Problem	Choose an orifice size and calculate coefficient.

Calculation

Use Equation 7, Page 50

Choose a $2\frac{1}{4} \times 6''$ orifice (See Example, page 25)

$C_W = 1{,}008$ G.P.H. . . . . Page 67

$\frac{M}{327.2} = 1.0$

$F_s = 1.0$ . . . . Page 57

$F_d\sqrt{F_T} = 1.108$ . . . . Page 58

$F_e = 1.0015$ . . . . Page 60

$C_M = 1{,}008 \times 1.0 \times 1.108 \times 1.0015 = 1{,}119$ G.P.H.

ILLUSTRATING FLOW NOZZLE CALCULATION

Flow	125 G.P.M. Max. Use Chart 898098, range 0–125
Pipe Size	2″ Std. wt., 2.067″ I.D.
Flowing Fluid	Oil, 50° A.P.I.
Fluid on Mercury . . .	Oil, 50° A.P.I.
Flowing Temperature .	207° F.
Orifice Plate Material .	Steel
Differential Range . . .	100″ Water, dry calibration
Tap Location	See alternative methods below
Viscosity	Negligible
Problem	Calculate orifice size for direct-reading meter

Calculation

Use Equation 1, Page 50

V_m = 125 G.P.M.

M = 5.453 . . . . Page 55

D^2 = 4.272 . . . . Page 56

F_s = 1.0 . . . . Page 57

$F_d\sqrt{F_T}$ = 1.095 . . . . Page 58

F_e = 1.0019 . . . . Page 60

$\sqrt{h_m}$ = 10 . . . . Page 62

$$S = \frac{125}{5.453 \times 4.272 \times 1.0 \times 1.095 \times 1.0019 \times 10} = .4891$$

It will be noted that this value is too high to reach on the orifice S curve, Fig. 2631C, indicating that the flow is excessive. There are four alternative methods of handling this situation:

1. Increase the differential range; i.e., $h_m = 200$, $\sqrt{h_m} = 14.14$

$$\text{Then } S = \frac{125}{5.453 \times 4.272 \times 1.0 \times 1.095 \times 1.0019 \times 14.14} = .3459$$

$$d/D = .6978; \quad d = .6978 \times 2.067'' = 1.442''$$

ILLUSTRATING $2\frac{1}{2}$ AND 8 PIPE DIAMETER TAP CALCULATION

Flow	7,500 bbl./day max. Use Chart 898097, range 0–75
Pipe Size	3″ Schedule 40, 3.068″ I.D.
Flowing Fluid	Oil, 45° A.P.I.
Fluid on Mercury . . .	Oil, 45° A.P.I.
Flowing Temperature .	200° F.
Orifice Plate Material .	Steel
Differential Range . . .	100″ Water, dry calibration
Taps	$2\frac{1}{2}$ P.D. upstream and 8 P.D. downstream

Calculation

Use Equation 1, Page 50

V_m = 7,500 bbl./day

M = 187 . . . . Page 55

D^2 = 9.413 . . . . Page 56

F_s = 1.0 . . . . Page 57

$F_d\sqrt{F_T}$ = 1.082 . . . . Page 58

F_e = 1.0019 . . . . Page 60

$\sqrt{h_m}$ = 10 . . . . Page 62

$$S = \frac{7{,}500}{187 \times 9.413 \times 1.0 \times 1.082 \times 1.0019 \times 10} = .3930$$

d/D = .6575 . . . . Page 133

d = .6575 × 3.068″ = 2.017″

ILLUSTRATING VENA CONTRACTA TAPS

Flow	1,250 G.P.M. Max. Use Chart 898098, range 0–125
Pipe Size	10″ Schedule 40, 10.02″ I.D.
Flowing Fluid	Calcium chloride solution Sp. Gr. = 1.0047

Fluid on Mercury . . .	Salt solution Sp. Gr. = 1.0047
Flowing Temperature .	104° F.
Orifice Plate Material .	Stainless Steel, Type 410
Differential Range . . .	50″ Water, dry calibration
Tap Location	Vena Contracta, 10″ up and 5″ downstream
Viscosity in Stokes . .	.01
Problem	Calculate orifice size for direct-reading meter.

Calculation

Use Equation 1, Page 50

V_m = 1,250 G.P.M.
M = 5.453 . . . . Page 55
D^2 = 100.4 . . . . Page 56
F_s = 1.0 . . . . Page 57
F_d = .997 . . . . Page 21
$\sqrt{F_T}$ = .996 (assuming same as water and taken from Fig. 8634, page 61)
F_e = 1.0005 . . . . Page 60
$\sqrt{h_m}$ = 7.071 . . . . Page 62

$$S = \frac{1{,}250}{5.453 \times 100.4 \times .997 \times .996 \times 1.0005 \times 7.071} = .3250$$

d/D = .6815
d = 10.02 × .6815 = 6.83″
Assuming a normal flow of 1000 G.P.M.

From Equation 18, page 51 $\frac{\text{Ind. G.P.H.}}{dt_s} = \frac{60{,}000}{6.83 \times 4.65} = 1{,}889$

Correction Factor = .984 (See page 44)

Corrected $S = \frac{.3250}{.984} = .3303$

d/D = .6857 . . . . Page 65
D = .6857 × 10.02″ = 6.871″

ILLUSTRATING MEASUREMENT OF COMPRESSIBLE OIL

Flow	150 G.P.M. Max. Use Chart 898145, range 0–15
Pipe Size	4″ Std. wt., 4.026″ I.D.
Flowing Fluid	Iso-octane
Fluid on Mercury . . .	Prestone and Water, Sp. Gr. 1.06
Flowing Temperature .	430° F.
Orifice Plate Material .	Steel
Differential Range . . .	100″ Water, dry calibration
Flowing Pressure . . .	1480 lbs./sq. in. Gauge
Tap Location	Flange
Problem	Calculate orifice size for direct-reading meter

Calculation

Use Equation 1, Page 50

V_m = 150 G.P.M.

M = 5.453 . . . . Page 55

D^2 = 16.21 . . . . Page 56

A.P.I. Gravity = 71.8° . . . . Page 13

Critical Temperature = 530.6° F. . . . . Page 13

Critical Pressure = 360# . . . . Page 13

$$T_R = \frac{460 + 430}{460 + 530.6} = \frac{890}{990.6} = .899$$

$$P_R = \frac{1480 + 14.7}{360} = 4.15$$

F_p = 1.034 . . . . Page 18

$\sqrt{F_T}$ = .843 . . . . Page 16

F_s = .985 . . . . Page 57

F_d = 1.213 . . . . Page 19

F_e = 1.0052 . . . . Page 60

$\sqrt{h_m}$ = 10 . . . . Page 62

$$S = \frac{150}{5.453 \times 16.21 \times 1.034 \times .843 \times .985 \times 1.213 \times 1.0052 \times 10} = .1621$$

d/D = .5079 . . . . Page 65

d = .5079 × 4.026″ = 2.045″

ILLUSTRATING MEASUREMENT OF LIQUID ANHYDROUS AMMONIA

Flow	9,000 lbs./hr. max. Use Chart 898128, range 0–30
Line Size	2″ Std. wt., 2.067″ I.D.
Flowing Fluid	Liquid Anhydrous Ammonia
Fluid on Mercury	Aquaseal, Sp. Gr. = 1.05
Flowing Temperature . .	70° F.
Orifice Plate Material . .	Steel
Differential Range . . .	20″ Water, dry calibration
Tap Location	Flange
Problem	Calculate an orifice size for direct-reading meter.

Calculation

Use Equation 12, Page 51

$W_m = 9{,}000$ lbs./hr.

$N = 2728$ . . . . Page 55

$D^2 = 4.272$ . . . . Page 56

$G_f = \dfrac{1}{.02632 \times 62.37} = .6092$ (.02632 = Specific volume from Saturated Ammonia Tables, Marks' Handbook)

$A = .781$ . . . . Page 68

$B = .998$ . . . . Page 70

$F_e = 1.0001$ . . . . Page 60

$\sqrt{h_m} = 4.472$ . . . . Page 62

$$S = \frac{9{,}000}{2728 \times 4.272 \times .781 \times .998 \times 1.0001 \times 4.472} = .2215$$

$d/D = .5830$ . . . . Page 65

$d = .5830 \times 2.067'' = 1.205''$

ILLUSTRATING MEASUREMENT WITH GAS CONTACTING MERCURY

Flow	15,000 lbs./hr. maximum. Use Chart 898145, range 0–15
Pipe Size	2″ Std. wt., 2.067″ I.D.
Flowing Fluid	Liquid Chlorine, Sp. Gr. 1.45 at 43° F.
Fluid on Mercury . . .	CO_2 purge, Sp. Gr. 1.529 compared to air
Flowing Temperature . .	43° F.
Orifice Material	KA_2SMO, Stainless Steel, Type 316
Differential Range . . .	20″ Water, dry calibration
Tap Location	Flange
Problem	Calculate an orifice size for direct-reading meter

Calculation

Use Equation 12, Page 51

W_m = 15,000 lbs./hr.

N = 2728 . . . . Page 55

G_s = Assume zero (For a gas, may be calculated from $G_s = \frac{.0433\ P \times G_a}{T}$ in which P is absolute pressure, lbs./sq. in.; G_a is specific gravity compared to air; T is absolute temperature °F.)

A = 1.204 . . . . Page 69

B = 1.039 . . . . Page 70

F_e = .9997 . . . . Page 60

$\sqrt{h_m}$ = 4.472 . . . . Page 62

$$S = \frac{15{,}000}{2728 \times 4.272 \times 1.204 \times 1.039 \times .9997 \times 4.472} = .2301$$

d/D = .5927 . . . . Page 65

d = .5927 × 2.067″ = 1.225

ILLUSTRATING PITOT TUBE CALCULATION

Pipe Size	10″ Cast Iron, 10″ I.D.
Fluid Contacting Mercury	Water Sp. Gr. = 1.0
Flowing Liquid	Water
Flowing Temperature . .	150° F.
Pipe Material	Steel
Differential Range . . .	100″ Water, dry calibration
Problem	Find rate of flow in G.P.H. at maximum differential and chart multiplier for chart 898074, range 0–10 square root.

Calculation

Use Equation 5, Page 50

Assume $\frac{\text{Average Velocity}}{\text{Maximum Velocity}} = .82 \quad S = .82 \times .825$ . . Page 34

$M = 327.2$ . . . . Page 55

$S = .82 \times .825$ . . . . Page 34

$D^2 = 100$ . . . . Page 56

$F_s = 1.0$ . . . . Page 57

$F_d\sqrt{F_T} = .99$ . . . . Page 61

$F_e = 1.0012$ . . . . Page 60

$\sqrt{h_m} = 10$ . . . . Page 62

$V = 327.2 \times .82 \times .825 \times 100 \times 1.0 \times .99 \times 1.0012 \times 10$
$= 219{,}400$

Viscosity in centipoises = .4 (Smithsonian Physical Tables)

$\frac{\text{G.P.H.}}{dt_s} = \frac{219{,}400}{4.65 \times 10 \times .4} = 11{,}800$ . . See Eq. 18, P. 51

For values higher than maximum shown in Fig. 4577, page 34,

assume $\frac{\text{Average Velocity}}{\text{Maximum Velocity}} = .82$

True Maximum Flow = 1.000 × 219,400 = 219,400 G.P.H.

Multiplier for 0–10 square root chart = $\frac{219{,}400 \text{ G.P.H.}}{10}$ = 21,940 G.P.H.

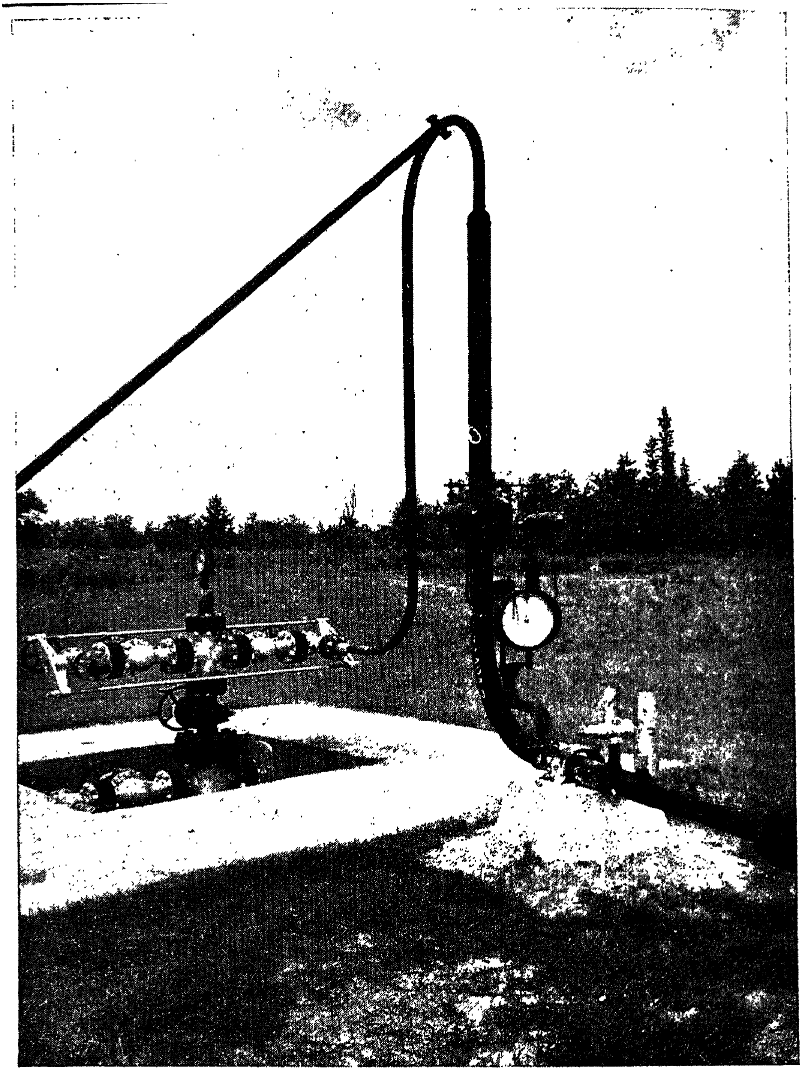


Fig. 8737
Foxboro Flow Meter at one of the plants of the Cotton Valley Operators Committee, Cotton Valley, Louisiana

PART II

Gas Flow Computations

GAS FLOW COMPUTATIONS

American Gas Association, Measurement Committee Report No. 1

Section I of Part II is based upon the coefficients recommended in the above report. These coefficients were used universally before the publication of Report No. 2, and, although officially superseded by Report No. 2 of May 1935, are still used by a number of companies.

To distinguish between the earlier and the later data, the earlier coefficients will hereafter be designated as "Report No. 1 Coefficients." The later data will be designated as "Report No. 2 Coefficients."

American Gas Association, Measurement Committee Report No. 2

For maximum accuracy we recommend the use of the procedure outlined in Section V, based on A. G. A. Committee Report No. 2.

GAS FLOW COMPUTATIONS

Gas flow measurement by orifice meter consists of recording two variables: the static pressure* and the differential pressure across a known orifice plate; and computing the flow from these records.

The computation of gas flow is divided into two important sections.

The *First Section* describes the *derivation* of the coefficient for a given orifice and a given set of conditions. Corrections for variations from standard conditions are also discussed in this section. Data is given for computing orifice sizes for direct reading or integrating gas flow meters.

The *Second Section* explains the *use* of the coefficient in computing the total flow from the records of the differential and static pressures.

Other sections contain information on the Direct-Reading Gas Flow Meter, the Square Root Planimeter and the Fundamentals of Commercial Measurement.

Pressure Taps

Flange connections are those with centers located 1″ upstream from the upstream face of the orifice and 1⅛″ to 1¼″ downstream from the upstream face of the orifice plate. These taps are properly located in the standard commercial orifice flange union supplied by THE FOXBORO COMPANY.

Pipe connections or full-flow connections are those located at 2½ pipe diameters upstream from the orifice plate, and 8 pipe diameters downstream. The distances should be measured from the upstream face of the plate to the center of the tapped hole.

*Downstream pressure when using flange connections; upstream, when using pipe connections.

Part II

Report No. 1

COEFFICIENTS ‡

There are several factors which affect the true flow measurement. Many of these are constant for a given installation. Their effects are combined in a figure called the "coefficient." Therefore, a coefficient in its application to the computation of gas flow is a multiplier. It is a figure which, multiplied by the extension† obtained from the two recorded variables, the static and differential pressure, gives the amount of gas passed in a certain period of time.

The numerical value of an hourly coefficient is the actual number of cubic feet passed in an hour at a differential pressure of one inch and an absolute static pressure of one pound. By absolute static pressure is meant the pressure above absolute vacuum. Each size orifice has its own coefficient, and each coefficient is constant for its respective orifice under any given conditions of flow.

The formula for the coefficient C_a at 14.4 lbs. per sq. in. absolute pressure base, 520° F. absolute temperature base, 520° F. absolute flowing temperature and 1.0 gravity is as follows:

$\mathbf{C_a = K\ SD^2}$ (S for flange taps $= S_f$; for pipe taps S_p)* ***Equation 51***

For definition and values of K, refer to page 112.

Values of C_a for either flange or pipe taps may be obtained from Tables. Additional coefficients for line sizes and orifice sizes not

† The extension is the product of the square root of the average differential pressure and the average absolute static pressure. For detailed explanation see Section II.

* NOTE: The quantity SD^2 has been used instead of the usual Ed^2. The results obtained are exactly the same, S being $\frac{Ed^2}{D^2}$. The use of the term S eliminates one variable from the equation and greatly simplifies orifice calculations.

Actual line size is used for all computations on pipe connections. Nominal sizes are used in computations on flange taps to agree with the method of derivation.

‡ Do not confuse the term coefficient as used in this handbook with the hydraulic coefficient as used in hydraulics text books. Read the definition carefully.

given in the table may be computed from the foregoing formula. Values of S_p may be obtained from Table XXVI or computed from the following formula:

$$S_p = .58925\frac{d^2}{D^2} + .2725\frac{d^3}{D^3} - .825\frac{d^4}{D^4} + 1.75\frac{d^5}{D^5}. \quad \textit{Equation 52}$$

Values of S_f may be obtained from Table XXV or computed from the following formula:

$$S_f = .606\frac{d^2}{D^2} + 1.25\frac{d^2}{D^2}\left(\frac{d}{D} - .41\right)^2 \text{ above } \frac{d}{D} = .41 \text{ and}$$

$$S_f = .606\frac{d^2}{D^2} \text{ below } \frac{d}{D} = .41 \quad . \; . \; . \; . \; . \; . \; . \quad \textit{Equation 53}$$

The method of deriving C_a for pipe connections is illustrated by the following example:

D = Line Size = 8.071 actual internal diameter.

d = Orifice Size = 3.5.

$$\frac{d}{D} = \frac{3.5}{8.071} = .4337$$

S_p = .1307 from Table XXVI

$C_{ap} = 345.755 \times .1307 \times 65.14 = 2944$

Fifteen-minute coefficients are obtained by dividing the hourly coefficients by four. Likewise, twenty-four-hour coefficients are obtained by multiplying the hourly coefficient by twenty-four.

Correcting Coefficients

All coefficients in the following table are based on 1.0 specific gravity, 14.4 lbs. per sq. in. absolute pressure base, 60° flowing temperature, and 60° temperature base. All coefficients before being used in the final computation of flow should be corrected for actual specific gravity, contract pressure base, actual or assumed flowing temperature, and contract temperature base.

All correction factors are the same for pipe or full-flow connections as for flange connections. Values of C_a and C_{ap} may be obtained from the tables of basic coefficients in the following pages.

For Routine Calculations, use Index, page 210.

Equations (using Report No. 1 Coefficients)

The flow for any hour is equal to:

$$Q = \mathbf{C_a \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv} \times \sqrt{h} \times \sqrt{P}}$$

for flange taps, and *Equation 54*

$$Q = \mathbf{C_{ap} \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv} \times \sqrt{h} \times \sqrt{P}}$$

for pipe taps *Equation 55*

Q = Rate of flow in cubic feet per hour.
C_a = Flange coefficient for air at 14.4 lbs./sq. in. absolute and 60° F. See pages 94 and 95.
C_{ap} = Pipe coefficient for air at 14.4 lbs/sq. in. absolute and 60° F. See pages 96 and 97.
F_{gp} = Correction for specific gravity and contract pressure base. See pages 98–102 inclusive.
F_t = Correction for flowing temperature. See page 104.
F_{tb} = Correction for contract temperature base. See page 105.
F_m = Correction for moisture. See page 93.
F_{pv} = Correction for supercompressibility. See pages 196–206.
$\sqrt{h}$ = Square root of differential pressure in inches of water. See page 150.
$\sqrt{P}$ = Square root of absolute static pressure in lbs./sq.in. See pages 151–153 inclusive.

The period method of chart computation involves calculating the flow for each period separately. These amounts are added together to obtain the total.

For convenient use in chart calculations, the corrected coefficient, C, is computed from the constant portion of equation 54 or 55 above.

C for flange taps $= \mathbf{C_a \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv}}$ *Equation 56*

C for pipe taps $= \mathbf{C_{ap} \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv}}$ *Equation 57*

Then $Q = \mathbf{C\sqrt{h}\sqrt{P}}$

Correction Factors

The basic coefficients have been figured on standard conditions of flow, but as flowing conditions vary from time to time — particularly the flowing temperature and the specific gravity — it is necessary to make corrections for the new determinations.

Tables of factors for adjusting basic coefficients have been carefully prepared to simplify the actual computations required to make any correction, and they cover the variable factors of the coefficient equation.

Flowing Temperature

The formula for flowing temperature correction is as follows:

$$F_t = \sqrt{\frac{T_{fo}}{T_{fn}}} \qquad \text{Equation 58}$$

F_t = correction factor for flowing temperature, values of which may be found in table XXIII on page 104.

T_{fo} = absolute temperature on which the original coefficient is based.

T_{fn} = absolute temperature of flowing gas.

Temperature Base

The formula for temperature base correction factor is:

$$F_{tb} = \frac{T_{Bn}}{T_{Bo}} \qquad \text{Equation 59}$$

in which

F_{tb} = correction factor for temperature base, values of which are found in table XXIV, page 105.

T_{Bo} = temperature base of original coefficient (absolute).

T_{Bn} = new temperature base (absolute).

Combined Correction Factor for Gravity and Pressure Base

The formula for the combined correction factor for gravity and pressure base is:

$$F_{gp} = \frac{P_{Bo}}{P_{Bn}} \sqrt{\frac{G_o}{G_n}} \qquad \textit{Equation 60}$$

Barometer Correction

We advise basing all coefficients on an absolute pressure base. If this is done there will be no barometer correction to the coefficient. Otherwise, the unit of measurement is elastic and measurements made at a high altitude will differ from those made at sea level, even though the same gas is being measured.

The foregoing statements do not apply to extensions or static pressure multipliers. These should be based upon the actual barometric pressure at the location of the meter.

Standard extension books are based upon a barometer of 14.4 lbs. per square inch. Tables for a few other barometric pressures which are considered average for given districts are available in some special instances.

The standard extension books based upon 14.4 lbs. per square inch barometer or multiplier tables, pages 150-153 may be used if the static pressure pen is displaced from actual correct gauge readings by the amount of the difference between 14.4 and the actual average barometric pressure at the Meter location.

For instance, suppose the barometric pressure were 12 lbs. per square inch, the difference between 14.4 and 12 is 2.4 lbs. The pressure pen would be made to read 2.4 lbs. per square inch low in comparison with the readings of a Test Gauge placed on the static Meter connection.*

* NOTE: The static meter connection is taken from the downstream connection when using flange taps, and from the upstream connection when using pipe taps. This is on account of the difference in the procedure used when deriving the values of E and S.

Corrections for Moisture

Some contracts involve reducing the volume of flowing gas to a specified state of relative humidity. The general formula for this correction is as follows:

$$F_m = \frac{P - R_f P_{wf}}{P} \times \frac{P_B}{P_B - R_b P_{wb}} \text{ (general formula) } \textit{Equation 61}$$

In which

F_m = the moisture correction factor

P = flowing pressure in pounds per square inch absolute

R_f = % relative humidity of flowing gas ÷ 100.

P_{wf} = water vapor pressure at flowing temperature, pounds per square inch absolute.

P_B = pressure base, pounds per square inch absolute.

R_b = % relative humidity specified by contract ÷ 100.

P_{wb} = water vapor pressure at base temperature, pounds per square inch absolute.

Natural gas, as delivered to the city gate may usually be considered dry, in which case $R_f = 0$ and

$$F_m = \frac{P_B}{P_B - R_b P_{wb}} \text{ (for dry gas } \textit{only}\text{). . . . . } \textit{Equation 62}$$

The value of P_{wf} may be read from the following table using the flowing temperature of the gas. The value of P_{wb} is read from the same table using the base temperature of the gas.

TABLE XIX

WATER VAPOR PRESSURE, P_w, IN POUNDS PER SQUARE INCH

Temp.	+0°	+1°	+2°	+3°	+4°	+5°	+6°	+7°	+8°	+9°
30°	....	....	.0887	.0923	.0961	.1000	.1041	.1083	.1126	.1171
40°	.1217	.1265	.1315	.1367	.1420	.1475	.1532	.1591	.1652	.1715
50°	.1780	.1848	.1918	.1989	.2063	.2140	.2219	.2300	.2384	.2471
60°	.2561	.2654	.2749	.2848	.2949	.3054	.3162	.3273	.3388	.3506
70°	.3628	.3754	.3883	.4016	.4153	.4295	.4440	.4590	.4744	.4903
80°	.5067	.5236	.5409	.5588	.5772	.5960	.6153	.6352	.6555	.6765
90°	.6980	.7201	.7429	.7662	.7902	.8149	.8403	.8663	.8930	.9205
100°	.9487	.9776	1.0072	1.0377	1.0689	1.1009	1.1338	1.1675	1.2020	1.2375

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Basic Orifice Coefficients
Flange Connections
TABLE XVIII
$$C_a = 345.92\ SD^2$$

Base Temperature 60° F.; Flowing Temperature 60° F.;
Base Pressure 14.4 Lbs./Sq. In.; Specific Gravity 1.0

Orifice Dia.	Pipe Sizes — Nominal and Actual Diameters							
	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
0								
1/8	3.275	3.275	3.275	3.275	3.275	3.275	3.275	3.275
1/4	13.10	13.10	13.10	13.10	13.10	13.10	13.10	13.10
3/8	29.48	29.48	29.48	29.48	29.48	29.48	29.48	29.48
1/2	52.41	52.41	52.41	52.41	52.41	52.41	52.41	52.41
5/8	81.89	81.89	81.89	81.89	81.89	81.89	81.89	81.89
3/4	117.9	117.9	117.9	117.9	117.9	117.9	117.9	117.9
7/8	160.7	160.5	160.5	160.5	160.5	160.5	160.5	160.5
1	213.1	209.6	209.6	209.6	209.6	209.6	209.6	209.6
1/8	278.0	265.3	265.3	265.3	265.3	265.3	265.3	265.3
1/4	....	327.6	327.5	327.5	327.5	327.5	327.5	327.5
3/8	....	398.2	396.3	396.3	396.3	396.3	396.3	396.3
1/2	....	479.5	471.7	471.7	471.7	471.7	471.7	471.7
5/8	....	573.3	553.5	553.5	553.5	553.5	553.5	553.5
3/4	....	681.8	643.0	642.0	642.0	642.0	642.0	642.0
7/8	....	....	742.2	737.0	737.0	737.0	737.0	737.0
2	....	....	852.5	838.5	838.5	838.5	838.5	838.5
1/8	....	....	975.3	946.6	946.6	946.6	946.6	946.6
1/4	....	....	1112	1061	1061	1061	1061	1061
3/8	....	....	1265	1182	1182	1182	1182	1182
1/2	....	....	....	1310	1310	1310	1310	1310
5/8	....	....	....	1447	1444	1444	1444	1444
3/4	....	....	....	1593	1585	1585	1585	1585
7/8	....	....	....	1750	1733	1733	1733	1733
3	....	....	....	1918	1887	1887	1887	1887
1/8	....	....	....	2099	2047	2047	2047	2047
1/4	....	....	....	2293	2214	2214	2214	2214
3/8	....	....	....	2502	2389	2388	2388	2388
1/2	....	....	....	2727	2572	2568	2568	2568
5/8	....	....	....	2969	2765	2755	2755	2755
3/4	....	....	....	....	2969	2948	2948	2948
7/8	....	....	....	....	3184	3148	3148	3148
4	....	....	....	....	3410	3354	3354	3354
1/8	....	....	....	....	3649	3567	3567	3567
1/4	....	....	....	....	3901	3788	3786	3786
3/8	....	....	....	....	4168	4019	4012	4012
1/2	....	....	....	....	4449	4259	4245	4245
5/8	....	....	....	....	4745	4509	4484	4484
3/4	....	....	....	....	5059	4771	4730	4730
7/8	....	....	....	....	5390	5044	4982	4982
5	....	....	....	....	....	5328	5241	5241
1/8	....	....	....	....	....	5625	5509	5506
1/4	....	....	....	....	....	5935	5787	5778
3/8	....	....	....	....	....	6259	6074	6056
1/2	....	....	....	....	....	6598	6372	6341
5/8	....	....	....	....	....	6951	6680	6633
3/4	....	....	....	....	....	7320	6999	6931
7/8	....	....	....	....	....	7706	7330	7235

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Basic Orifice Coefficients
Flange Connections
TABLE XVIII — *Continued*
$C_a = 345.92\ SD^2$

Base Temperature 60° F.; Flowing Temperature 60° F.;
Base Pressure 14.4 Lbs./Sq. In.; Specific Gravity 1.0

Ori-fice Dia.	Pipe Sizes — Nominal and Actual Diameters							
	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
6	....	....	....	....	....	8109	7,673	7,547
⅛	....	....	....	....	....	....	8,028	7,864
¼	....	....	....	....	....	....	8,396	8,189
⅜	....	....	....	....	....	....	8,778	8,521
½	....	....	....	....	....	....	9,174	8,862
⅝	....	....	....	....	....	....	9,584	9,212
¾	....	....	....	....	....	....	10,010	9,572
⅞	....	....	....	....	....	....	10,440	9,936
7	....	....	....	....	....	....	10,910	10,320
⅛	....	....	....	....	....	....	11,380	10,710
¼	....	....	....	....	....	....	11,870	11,120
⅜	....	....	....	....	....	....	....	11,530
½	....	....	....	....	....	....	....	11,940
⅝	....	....	....	....	....	....	....	12,390
¾	....	....	....	....	....	....	....	12,840
⅞	....	....	....	....	....	....	....	13,300
8	....	....	....	....	....	....	....	13,780
⅛	....	....	....	....	....	....	....	14,270
¼	....	....	....	....	....	....	....	14,770
⅜	....	....	....	....	....	....	....	15,290
½	....	....	....	....	....	....	....	15,820
⅝	....	....	....	....	....	....	....	16,370
¾	....	....	....	....	....	....	....	16,940
⅞	....	....	....	....	....	....	....	17,520
9	....	....	....	....	....	....	....	18,120
⅛	....	....	....	....	....	....	....	18,730
¼	....	....	....	....	....	....	....	19,370
..	....	....	....	....	....	....	....	....
..	....	....	....	....	....	....	....	....
..	....	....	....	....	....	....	....	....
..	....	....	....	....	....	....	....	....

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Basic Orifice Coefficients
For 2½ and 8 Pipe Diam. Connections
TABLE XX

$C_{ap} = 345.755\ SD^2$

Base Temperature 60° F.; Flowing Temperature 60° F.;
Base Pressure 14.4 Lbs./Sq. In.; Specific Gravity 1.0

Orifice	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.09
⅛	3.258	3.237	3.225	3.212	3.205	3.201	3.198
¼	13.25	13.12	13.04	12.95	12.90	12.87	12.85
⅜	30.24	29.83	29.61	29.34	29.19	29.09	29.03
½	54.60	53.53	53.05	52.48	52.16	51.94	51.80
⅝	87.06	84.46	83.50	82.45	81.87	81.49	81.22
¾	129.0	122.9	121.1	119.4	118.4	117.8	117.4
⅞	182.5	169.5	166.1	163.2	161.8	160.9	160.2
1	251.1	225.1	218.8	214.2	212.2	210.8	209.9
1⅛	339.3	290.8	279.7	272.4	269.5	267.7	266.5
1¼	453.5	368.6	349.4	338.0	334.0	331.5	329.8
1⅜	601.8	459.7	428.7	411.2	405.5	402.3	400.2
1½	794.5	567.7	518.7	492.2	484.4	480.1	477.4
1⅝	....	695.9	620.8	581.3	570.6	565.1	561.7
1¾	....	848.2	736.5	679.0	664.3	657.3	653.0
1⅞	....	1030.	867.9	785.7	765.8	756.7	751.4
2	....	1246.	1017.	901.9	875.1	863.5	857.0
2⅛	....	1505.	1188.	1029.	992.6	977.8	969.8
2¼	....	1813.	1382.	1166.	1119.	1100.	1090.
2⅜	....	....	1603.	1316.	1253.	1229.	1217.
2½	....	....	1857.	1478.	1397.	1367.	1352.
2⅝	....	....	2147.	1655.	1551.	1513.	1495.
2¾	....	....	2479.	1847.	1714.	1667.	1645.
2⅞	....	....	2859.	2056.	1888.	1829.	1803.
3	....	....	3293.	2284.	2074.	2001.	1969.
3⅛	....	....	....	2532.	2271.	2182.	2143.
3¼	....	....	....	2804.	2481.	2372.	2326.
3⅜	....	....	....	3099.	2705.	2572.	2517.
3½	....	....	....	3423.	2944.	2783.	2717.
3⅝	....	....	....	3776.	3198.	3004.	2926.
3¾	....	....	....	4162.	3468.	3237.	3144.
3⅞	....	....	....	4584.	3757.	3482.	3372.
4	....	....	....	5046.	4064.	3739.	3610.
4⅛	....	....	....	5551.	4393.	4009.	3858.
4¼	....	....	....	6103.	4743.	4293.	4116.
4⅜	....	....	....	6707.	5118.	4592.	4386.
4½	....	....	....	7366.	5517.	4906.	4667.
4⅝	....	....	....	....	5945.	5237.	4961.
4¾	....	....	....	....	6402.	5585.	5267.
4⅞	....	....	....	....	6890.	5951.	5585.

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Basic Orifice Coefficients
For 2½ and 8 Pipe Diam. Connections
TABLE XX — *Continued*

$$C_{ap} = 345.755\ SD^2$$

Base Temperature 60° F.; Flowing Temperature 60° F.;
Base Pressure 14.4 Lbs./Sq. In.; Specific Gravity 1.0

Orifice	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.09
5	....	....	....	....	7412.	6336.	5918.
5⅛	....	....	....	....	7971.	6742.	6265.
5¼	....	....	....	....	8568.	7169.	6626.
5⅜	....	....	....	....	9207.	7619.	7004.
5½	....	....	....	....	9890.	8093.	7397.
5⅝	....	....	....	....	10621.	8593.	7808.
5¾	....	....	....	....	11402.	9120.	8236.
5⅞	....	....	....	....	12238.	9676.	8684.
6	....	....	....	....	13130.	10262.	9151.
6⅛	....	....	....	....	....	10880.	9639.
6¼	....	....	....	....	....	11533.	10149.
6⅜	....	....	....	....	....	12220.	10681.
6½	....	....	....	....	....	12946.	11237.
6⅝	....	....	....	....	....	13712.	11819.
6¾	....	....	....	....	....	14520.	12426.
6⅞	....	....	....	....	....	15372.	13061.
7	....	....	....	....	....	16271.	13725.
7⅛	....	....	....	....	....	17219.	14419.
7¼	....	....	....	....	....	18219.	15145.
7⅜	....	....	....	....	....	19273.	15904.
7½	....	....	....	....	....	20385.	16698.
7⅝	....	....	....	....	....	....	17529.
7¾	....	....	....	....	....	....	18397.
7⅞	....	....	....	....	....	....	19305.
8	....	....	....	....	....	....	20255.
8⅛	....	....	....	....	....	....	21249.
8¼	....	....	....	....	....	....	22288.
8⅜	....	....	....	....	....	....	23375.
8½	....	....	....	....	....	....	24511.
8⅝	....	....	....	....	....	....	25699.
8¾	....	....	....	....	....	....	26942.
8⅞	....	....	....	....	....	....	28240.
9	....	....	....	....	....	....	29598.

Note. Coefficients for orifices whose d/D (ratio of orifice diameters to pipe diameters) are high, are underlined.

Correction Factor for Gravity and Pressure Base

TABLE XXI, F_{gp}

Contract Pressure Base

Above 14.4 lb.	0 lb.	4 oz.	8 oz.	10 oz.	1 lb.	2 lb.
Absolute Pressure Base	14.4 lb.	14.65 lb.	14.9 lb.	15.025 lb.	15.4 lb.	16.4 lb.
Flowing Gravity						
.560	1.3363	1.3135	1.2915	1.2807	1.2495	1.1733
.565	1.3304	1.3077	1.2857	1.2750	1.2440	1.1681
.570	1.3245	1.3019	1.2801	1.2694	1.2385	1.1630
.575	1.3188	1.2963	1.2745	1.2639	1.2331	1.1579
.580	1.3131	1.2907	1.2669	1.2584	1.2278	1.1529
.585	1.3074	1.2851	1.2636	1.2531	1.2225	1.1480
.590	1.3019	1.2797	1.2582	1.2477	1.2174	1.1431
.595	1.2964	1.2743	1.2529	1.2425	1.2122	1.1383
.600	1.2910	1.2690	1.2477	1.2373	1.2072	1.1336
.605	1.2856	1.2637	1.2425	1.2322	1.2022	1.1289
.610	1.2804	1.2585	1.2374	1.2271	1.1972	1.1242
.615	1.2752	1.2534	1.2324	1.2221	1.1923	1.1196
.620	1.2700	1.2483	1.2274	1.2172	1.1875	1.1151
.625	1.2649	1.2433	1.2225	1.2123	1.1828	1.1107
.630	1.2599	1.2384	1.2176	1.2075	1.1781	1.1062
.635	1.2549	1.2335	1.2128	1.2027	1.1734	1.1019
.640	1.2500	1.2287	1.2081	1.1980	1.1688	1.0976
.645	1.2451	1.2239	1.2034	1.1934	1.1643	1.0933
.650	1.2403	1.2192	1.1987	1.1888	1.1598	1.0891
.655	1.2356	1.2145	1.1941	1.1842	1.1554	1.0849
.660	1.2309	1.2099	1.1896	1.1797	1.1510	1.0808
.665	1.2263	1.2054	1.1851	1.1753	1.1467	1.0767
.670	1.2217	1.2008	1.1807	1.1709	1.1424	1.0727
.675	1.2172	1.1964	1.1763	1.1665	1.1381	1.0687
.680	1.2127	1.1920	1.1720	1.1622	1.1339	1.0648
.685	1.2082	1.1876	1.1677	1.1580	1.1298	1.0609
.690	1.2039	1.1833	1.1635	1.1538	1.1257	1.0570
.695	1.1995	1.1791	1.1593	1.1496	1.1216	1.0532
.700	1.1952	1.1748	1.1551	1.1455	1.1176	1.0495
.705	1.1910	1.1707	1.1510	1.1414	1.1136	1.0457
.710	1.1868	1.1665	1.1470	1.1374	1.1097	1.0421
.715	1.1826	1.1624	1.1429	1.1334	1.1058	1.0384
.720	1.1785	1.1584	1.1390	1.1295	1.1020	1.0348
.725	1.1744	1.1544	1.1350	1.1256	1.0982	1.0312
.730	1.1704	1.1504	1.1311	1.1217	1.0944	1.0277
.735	1.1664	1.1465	1.1273	1.1179	1.0907	1.0242
.740	1.1625	1.1426	1.1235	1.1141	1.0870	1.0207
.745	1.1586	1.1388	1.1197	1.1104	1.0833	1.0173
.750	1.1547	1.1350	1.1160	1.1067	1.0797	1.0139
.755	1.1509	1.1312	1.1123	1.1030	1.0761	1.0105
.760	1.1471	1.1275	1.1086	1.0994	1.0726	1.0072
.765	1.1433	1.1238	1.1050	1.0958	1.0691	1.0039
.770	1.1396	1.1202	1.1014	1.0922	1.0656	1.0006
.775	1.1359	1.1165	1.0978	1.0887	1.0622	.9974
.780	1.1323	1.1130	1.0943	1.0852	1.0588	.9942
.785	1.1287	1.1094	1.0908	1.0817	1.0554	.9910
.790	1.1251	1.1059	1.0874	1.0783	1.0520	.9879
.795	1.1215	1.1024	1.0839	1.0749	1.0487	.9845
.800	1.1180	1.0990	1.0805	1.0715	1.0454	.9813
.805	1.1146	1.0955	1.0772	1.0682	1.0422	.978[illegible]

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Correction Factor for Gravity and Pressure Base

TABLE XXI, F_{gp} — *continued*

Contract Pressure Base

Above 14.4 lb.	0 lb.	4 oz.	8 oz.	10 oz.	1 lb.	2 lb.
Absolute Pressure Base	14.4 lb.	14.65 lb.	14.9 lb.	15.025 lb.	15.4 lb.	16.4 lb.
Flowing Gravity						
.810	1.1111	1.0921	1.0738	1.0649	1.0390	.9756
.815	1.1077	1.0888	1.0705	1.0616	1.0358	.9726
.820	1.1043	1.0855	1.0673	1.0584	1.0326	.9696
.825	1.1010	1.0822	1.0640	1.0552	1.0295	.9667
.830	1.0976	1.0789	1.0608	1.0520	1.0264	.9638
.835	1.0944	1.0757	1.0576	1.0488	1.0233	.9609
.840	1.0911	1.0725	1.0545	1.0457	1.0202	.9580
.845	1.0879	1.0693	1.0514	1.0426	1.0172	.9552
.850	1.0847	1.0661	1.0483	1.0395	1.0142	.9524
.855	1.0815	1.0630	1.0452	1.0365	1.0113	.9496
.860	1.0783	1.0599	1.0421	1.0335	1.0083	.9468
.865	1.0752	1.0569	1.0391	1.0305	1.0054	.9441
.870	1.0721	1.0538	1.0361	1.0275	1.0025	.9414
.875	1.0690	1.0508	1.0332	1.0246	.9996	.9387
.880	1.0660	1.0478	1.0302	1.0217	.9968	.9360
.885	1.0630	1.0449	1.0273	1.0188	.9940	.9334
.890	1.0600	1.0419	1.0244	1.0159	.9912	.9307
.895	1.0570	1.0390	1.0216	1.0131	.9884	.9281
.900	1.0541	1.0361	1.0187	1.0102	.9856	.9255
.905	1.0512	1.0332	1.0159	1.0075	.9829	.9230
.910	1.0483	1.0304	1.0131	1.0047	.9802	.9204
.915	1.0454	1.0276	1.0103	1.0019	.9775	.9179
.920	1.0426	1.0248	1.0076	.9992	.9749	.9154
.925	1.0398	1.0220	1.0049	.9965	.9722	.9130
.930	1.0370	1.0193	1.0022	.9938	.9696	.9105
.935	1.0342	1.0165	.9995	.9912	.9670	.9081
.940	1.0314	1.0138	.9968	.9885	.9644	.9056
.945	1.0287	1.0111	.9942	.9859	.9619	.9032
.950	1.0260	1.0085	.9916	.9833	.9594	.9009
.955	1.0233	1.0058	.9890	.9807	.9568	.8985
.960	1.0206	1.0032	.9864	.9782	.9543	.8962
.965	1.0180	1.0006	.9838	.9756	.9519	.8938
.970	1.0153	.9980	.9813	.9731	.9494	.8915
.975	1.0127	.9955	.9788	.9706	.9470	.8892
.980	1.0102	.9929	.9763	.9681	.9446	.8870
.985	1.0076	.9904	.9738	.9657	.9422	.8847
.990	1.0050	.9879	.9713	.9632	.9398	.8825
.995	1.0025	.9854	.9689	.9608	.9374	.8803
1.000	1.0000	.9829	.9664	.9584	.9351	.8780
1.005	.9975	.9805	.9640	.9560	.9327	.8759
1.010	.9950	.9781	.9616	.9536	.9304	.8737
1.015	.9926	.9756	.9593	.9513	.9281	.8715
1.020	.9902	.9733	.9569	.9490	.9259	.8694
1.025	.9877	.9709	.9546	.9466	.9236	.8673
1.030	.9853	.9685	.9523	.9443	.9213	.8652
1.035	.9830	.9662	.9500	.9421	.9191	.8631
1.040	.9806	.9638	.9477	.9398	.9169	.8610
1.045	.9782	.9615	.9454	.9375	.9147	.8589
1.050	.9759	.9592	.9432	.9353	.9125	.8569
1.055	.9736	.9570	.9409	.9331	.9104	.8549

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Correction Factor for Gravity and Pressure Base

TABLE XXI, F_{gp} — *continued*

Contract Pressure Base

Above 14.4 lb.	0 lb.	4 oz.	8 oz.	10 oz.	1 lb.	2 lb.
Absolute Pressure Base	14.4 lb.	14.65 lb.	14.9 lb.	15.025 lb.	15.4 lb.	16.4 lb.
Flowing Gravity						
1.060	.9713	.9547	.9387	.9309	.9082	.8528
1.065	.9690	.9525	.9365	.9287	.9061	.8508
1.070	.9667	.9502	.9343	.9265	9040	.8488
1.075	.9645	.9480	.9321	9244	.9019	.8469
1.080	.9623	.9458	.9300	.9222	.8998	.8449
1.085	.9600	.9436	.9278	.9201	.8977	.8430
1.090	.9578	.9415	.9257	.9180	.8956	.8410
1.095	.9556	.9393	.9236	.9159	.8936	.8391
1.100	.9535	.9372	.9215	.9138	.8915	.8372
1.105	.9513	.9351	.9194	.9117	.8895	.8353
1.110	.9492	.9330	.9173	.9097	.8875	.8334
1.115	.9470	.9309	.9152	.9076	.8855	.8315
1.120	.9449	.9288	.9132	.9056	.8836	.8297
1.125	.9428	.9267	.9112	.9036	.8816	.8278
1.130	.9407	.9247	.9092	.9016	.8796	.8260
1.135	.9386	.9226	.9071	.8996	.8777	.8242
1.140	.9366	.9206	.9052	.8976	.8758	.8224
1.145	.9345	.9186	.9032	.8957	.8739	.8206
1.150	.9325	.9166	.9012	.8937	.8720	.8188
1.155	.9305	.9146	.8993	.8918	.8701	.8170
1.160	.9285	.9126	.8973	.8898	.8682	.8152
1.165	.9265	.9107	.8954	.8879	.8663	.8135
1.170	.9245	.9087	.8935	.8860	.8645	.8118
1.175	.9225	.9068	.8916	.8842	.8626	.8100
1.180	.9206	.9049	.8897	.8823	.8608	.8083
1.185	.9186	.9030	.8878	.8804	.8590	.8066
1.190	.9167	.9011	.8859	.8786	.8572	.8049
1.195	.9148	.8992	.8841	.8767	.8554	.8032
1.200	.9129	.8973	.8822	.8749	.8536	.8015
1.205	.9110	.8954	.8804	.8731	.8518	.7999
1.210	.9091	.8936	.8786	.8713	.8501	.7982
1.215	.9072	.8917	.8768	.8695	.8483	.7966
1.220	.9054	.8899	.8750	.8677	.8466	.7949
1.225	.9035	.8881	.8732	.8659	.8448	.7933
1.230	.9017	.8863	.8714	.8642	.8431	.7917
1.235	.8998	.8845	.8696	.8624	.8414	.7901
1.240	.8980	.8827	.8679	.8607	.8397	.7885
1.245	.8962	.8809	.8661	.8589	.8380	.7869
1.250	.8944	.8792	.8644	.8572	.8363	.7854
1.255	.8926	.8774	.8627	.8555	.8347	.7838
1.260	.8909	.8757	.8610	.8538	.8330	.7822
1.265	.8891	.8739	.8593	.8521	.8314	.7807
1.270	.8874	.8722	.8576	.8504	.8297	.7791
1.275	.8856	.8705	.8559	.8488	.8281	.7776
1.280	.8839	.8688	.8542	.8471	.8265	.7761
1.285	.8822	.8671	.8526	.8455	.8249	.7746
1.290	.8805	.8654	.8509	.8438	.8233	.7731
1.295	.8787	.8638	.8493	.8422	.8217	.7716
1.300	.8771	.8621	.8476	.8406	.8201	.7701
1.305	.8754	.8604	.8460	.8390	.8185	.7686

Continued on page 101

Correction Factor for Gravity and Pressure Base

TABLE XXI, F_{gp} — *continued*

Contract Pressure Base

Above 14.4 lb.	0 lb.	4 oz.	8 oz.	10 oz.	1 lb.	2 lb.
Absolute Pressure Base	14.4 lb.	14.65 lb.	14.9 lb.	15.025 lb.	15.4 lb.	16.4 lb.
Flowing Gravity						
1.310	.8737	.8588	.8444	.8374	.8170	.7672
1.315	.8720	.8572	.8428	.8358	.8154	.7657
1.320	.8704	.8555	.8412	.8342	.8139	.7642
1.325	.8687	.8539	.8396	.8326	.8123	.7628
1.330	.8671	.8523	.8380	.8310	.8108	.7614
1.335	.8655	.8507	.8364	.8295	.8093	.7599
1.340	.8639	.8491	.8349	.8279	.8078	.7585
1.345	.8623	.8475	.8333	.8264	.8063	.7571
1.350	.8607	.8460	.8318	.8249	.8048	.7557
1.355	.8591	.8444	.8302	.8233	.8033	.7543
1.360	.8575	.8429	.8287	.8218	.8018	.7529
1.365	.8559	.8413	.8272	.8203	.8003	.7515
1.370	.8544	.8398	.8257	.8188	.7989	.7502
1.375	.8528	.8383	.8242	.8173	.7974	.7488
1.380	.8513	.8367	.8227	.8158	.7960	.7474
1.385	.8497	.8352	.8212	.8144	.7945	.7461
1.390	.8482	.8337	.8197	.8129	.7931	.7448
1.395	.8467	.8322	.8183	.8114	.7917	.7434
1.400	.8452	.8307	.8168	.8100	.7903	.7421
1.405	.8436	.8293	.8153	.8086	.7889	.7408
1.410	.8422	.8278	.8139	.8071	.7875	.7395
1.415	.8407	.8263	.8125	.8057	.7861	.7381
1.420	.8392	.8249	.8110	.8043	.7847	.7368
1.425	.8377	.8234	.8096	.8029	.7833	.7355
1.430	.8362	.8220	.8082	.8015	.7819	.7343
1.435	.8348	.8205	.8068	.8001	.7806	.7330
1.440	.8333	.8191	.8054	.7987	.7792	.7317
1.445	.8319	.8177	.8040	.7973	.7779	.7304
1.450	.8305	.8163	.8026	.7959	.7765	.7292
1.455	.8290	.8149	.8012	.7945	.7752	.7279
1.460	.8276	.8135	.7998	.7932	.7739	.7267
1.465	.8262	.8121	.7985	.7918	.7725	.7254
1.470	.8248	.8107	.7971	.7905	.7712	.7242
1.475	.8234	.8093	.7958	.7891	.7699	.7230
1.480	.8220	.8080	.7944	.7878	.7686	.7218
1.485	.8206	.8066	.7931	.7865	.7673	.7205
1.490	.8192	.8053	.7917	.7852	.7660	.7193
1.495	.8179	.8039	.7904	.7838	.7648	.7181
1.500	.8165	.8026	.7891	.7825	.7635	.7169
1.505	.8151	.8012	.7878	.7812	.7622	.7157
1.510	.8138	.7999	.7865	.7799	.7609	.7145
1.515	.8124	.7986	.7852	.7786	.7597	.7134
1.520	.8111	.7973	.7839	.7774	.7584	.7122
1.525	.8098	.7960	.7826	.7761	.7572	.7110
1.530	.8085	.7947	.7813	.7748	.7560	.7099
1.535	.8071	.7934	.7800	.7736	.7547	.7087
1.540	.8058	.7921	.7788	.7723	.7535	7076
1.545	.8045	.7908	.7775	.7711	.7523	.7064
1.550	.8032	.7895	.7763	.7698	.7511	.7053
1.555	.8019	.7882	.7750	.7686	.7499	.7041

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Correction Factor for Gravity and Pressure Base

TABLE XXI, F_{gp} — *continued*

Contract Pressure Base

Above 14.4 lb.	0 lb.	4 oz.	8 oz.	10 oz.	1 lb.	2 lb.
Absolute Pressure Base	14.4 lb.	14.65 lb.	14.9 lb.	15.025 lb.	15.4 lb.	16.4 lb.
Flowing Gravity						
1.560	.8006	.7870	.7738	.7673	.7487	.7030
1.565	.7994	.7857	.7725	.7661	.7475	.7019
1.570	.7981	.7845	.7713	.7649	.7463	.7008
1.575	.7968	.7832	.7701	.7637	.7451	.6996
1.580	.7956	.7820	.7689	.7625	.7439	.6985
1.585	.7943	.7807	.7676	.7613	.7427	.6974
1.590	.7931	.7795	.7664	.7601	.7416	.6963
1.595	.7918	.7783	.7652	.7589	.7404	.6952
1.600	.7906	.7771	.7640	.7577	.7392	.6942
1.605	.7893	.7758	.7628	.7565	.7381	.6930
1.610	.7881	.7746	.7616	.7553	.7370	.6920
1.615	.7869	.7734	.7605	.7542	.7358	.6909
1.620	.7857	.7723	.7593	.7530	.7347	.6898
1.625	.7845	.7711	.7581	.7519	.7336	.6888
1.630	.7833	.7699	.7570	.7507	.7325	.6877
1.635	.7821	.7687	.7558	.7496	.7313	.6867
1.640	.7809	.7675	.7547	.7484	.7302	.6856
1.645	.7797	.7664	.7535	.7473	.7291	.6846
1.650	.7786	.7652	.7523	.7461	.7280	.6835
1.655	.7774	.7640	.7512	.7450	.7269	.6825
1.660	.7761	.7629	.7501	.7439	.7258	.6815
1.665	.7750	.7617	.7490	.7428	.7247	.6805
1.670	.7739	.7606	.7478	.7416	.7236	.6794
1.675	.7727	.7595	.7467	.7406	.7226	.6784
1.680	.7715	.7583	.7456	.7394	.7214	.6774
1.685	.7704	.7572	.7445	.7384	.7204	.6764
1.690	.7692	.7560	.7434	.7372	.7193	.6754
1.695	.7681	.7550	.7423	.7361	.7183	.6744
1.700	.7669	.7539	.7412	.7351	.7172	.6734
1.705	.7659	.7527	.7401	.7339	.7161	.6724
1.710	.7648	.7516	.7390	.7329	.7151	.6714
1.715	.7636	.7505	.7379	.7318	.7140	.6704
1.720	.7625	.7495	.7369	.7308	.7130	.6695
1.725	.7614	.7484	.7358	.7297	.7120	.6685
1.730	.7603	.7473	.7348	.7287	.7110	.6675
1.735	.7592	.7462	.7337	.7276	.7099	.6666
1.740	.7581	.7451	.7326	.7266	.7089	.6656
1.745	.7570	.7441	.7316	.7255	.7079	.6646
1.750	.7559	.7430	.7305	.7245	.7068	.6637
1.755	.7549	.7420	.7295	.7235	.7059	.6628
1.760	.7538	.7409	.7285	.7224	.7049	.6618
1.765	.7527	.7398	.7274	.7214	.7038	.6609
1.770	.7517	.7387	.7263	.7203	.7028	.6599
1.775	.7506	.7378	.7254	.7194	.7019	.6590
1.780	.7496	.7367	.7243	.7183	.7009	.6581
1.785	.7485	.7357	.7234	.7174	.6999	.6572
1.790	.7475	.7346	.7223	.7163	.6989	.6562
1.795	.7464	.7336	.7213	.7153	.6980	.6553
1.800	.7454	.7327	.7204	.7144	.6970	.6544

Correction Factor for Pressure Base

TABLE XXII, F_p

FACTORS FOR ADJUSTING BASIC COEFFICIENTS
from 0 lb. per sq. inch @ 14.4 lb. per sq. inch Barometer or
14.4 lb. per sq. inch. Absolute Pressure Base to
CONTRACT PRESSURE BASE

CONTRACT PRESSURE BASE			
Above 14.4		Absolute	
oz.	lb.	lb.	CORRECTION FACTOR
2	.125	14.525	.9914
4	.250	14.65	.9829
		14.7	.9796
		14.73	.9776
6	.375	14.775	.9746
8	.500	14.9	.9664
10	.625	15.025	.9584
12	.750	15.15	.9505
14	.875	15.275	.9427
16	1.000	15.40	.9351
18	1.125	15.525	.9275
20	1.250	15.65	.9201
22	1.375	15.775	.9128
24	1.500	15.90	.9057
26	1.625	16.025	.8986
28	1.750	16.15	.8916
30	1.875	16.275	.8848
32	2.000	16.40	.8780
34	2.125	16.525	.8714
36	2.250	16.65	.8649
38	2.375	16.775	.8584
40	2.500	16.90	.8521
42	2.625	17.025	.8458
44	2.750	17.15	.8397
46	2.875	17.275	.8336
48	3.000	17.40	.8276

Correction Factor for Flowing Temperature

TABLE XXIII, F_t

Factors for Adjusting Basic Coefficients

From Flowing Temperature of 60° F. to Temperature of Measurement

F°		F°		F°		F°	
1	1.0621	41	1.0188	81	.9804	121	.9460
2	1.0610	42	1.0178	82	.9795	122	.9452
3	1.0598	43	1.0168	83	.9786	123	.9444
4	1.0587	44	1.0158	84	.9777	124	.9436
5	1.0575	45	1.0148	85	.9768	125	.9428
6	1.0564	46	1.0138	86	.9759	126	.9420
7	1.0553	47	1.0128	87	.9750	127	.9412
8	1.0541	48	1.0118	88	.9741	128	.9404
9	1.0530	49	1.0108	89	.9732	129	.9396
10	1.0519	50	1.0098	90	.9723	130	.9388
11	1.0508	51	1.0088	91	.9714	131	.9380
12	1.0497	52	1.0078	92	.9706	132	.9372
13	1.0486	53	1.0068	93	.9697	133	.9364
14	1.0474	54	1.0058	94	.9688	134	.9356
15	1.0463	55	1.0049	95	.9679	135	.9348
16	1.0452	56	1.0039	96	.9671	136	.9340
17	1.0441	57	1.0029	97	.9662	137	.9332
18	1.0430	58	1.0019	98	.9653	138	.9325
19	1.0420	59	1.0010	99	.9645	139	.9317
20	1.0409	60	1.0000	100	.9636	140	.9309
21	1.0398	61	.9990	101	.9627	141	.9301
22	1.0387	62	.9981	102	.9619	142	.9294
23	1.0376	63	.9971	103	.9610	143	.9286
24	1.0366	64	.9962	104	.9602	144	.9278
25	1.0355	65	.9952	105	.9593	145	.9270
26	1.0344	66	.9943	106	.9585	146	.9263
27	1.0333	67	.9933	107	.9576	147	.9255
28	1.0323	68	.9924	108	.9568	148	.9248
29	1.0312	69	.9915	109	.9559	149	.9240
30	1.0302	70	.9905	110	.9551	150	.9232
31	1.0291	71	.9896	111	.9543	...	....
32	1.0281	72	.9887	112	.9534	...	....
33	1.0270	73	.9877	113	.9526	...	....
34	1.0260	74	.9868	114	.9518	...	....
35	1.0250	75	.9859	115	.9509	...	....
36	1.0239	76	.9850	116	.9501	...	....
37	1.0229	77	.9840	117	.9493	...	....
38	1.0219	78	.9831	118	.9485	...	....
39	1.0208	79	.9822	119	.9476	...	....
40	1.0198	80	.9813	120	.9468	...	....

Correction Factor for Temperature Base

TABLE XXIV, F_{tb}

Factors for Adjusting Basic Coefficients From Temperature Base of 60° F. to Contract Temperature Base

Temperature	Factor	Temperature	Factor
40	.9615	65	1.010
41	.9634	66	1.011
42	.9653	67	1.013
43	.9673	68	1.015
44	.9692	69	1.017
45	.9711	70	1.019
46	.9730	71	1.021
47	.9750	72	1.023
48	.9769	73	1.025
49	.9788	74	1.027
50	.9807	75	1.029
51	.9827	76	1.031
52	.9846	77	1.033
53	.9865	78	1.035
54	.9884	79	1.036
55	.9903	80	1.038
56	.9923	81	1.040
57	.9942	82	1.042
58	.9961	83	1.044
59	.9980	84	1.046
60	1.000	85	1.048
61	1.002	86	1.050
62	1.004	87	1.052
63	1.006	88	1.054
64	1.008	89	1.056
..	....	90	1.058

To correct an hourly coefficient that is on a temperature base of 60° to any other temperature base within the range of the above table, multiply that coefficient by the factor corresponding to the new temperature base.

If the hourly coefficient is on any temperature base other than 60°, find the hourly coefficient for 60° from the coefficient tables and multiply it by the factor in table above corresponding to the new temperature base.

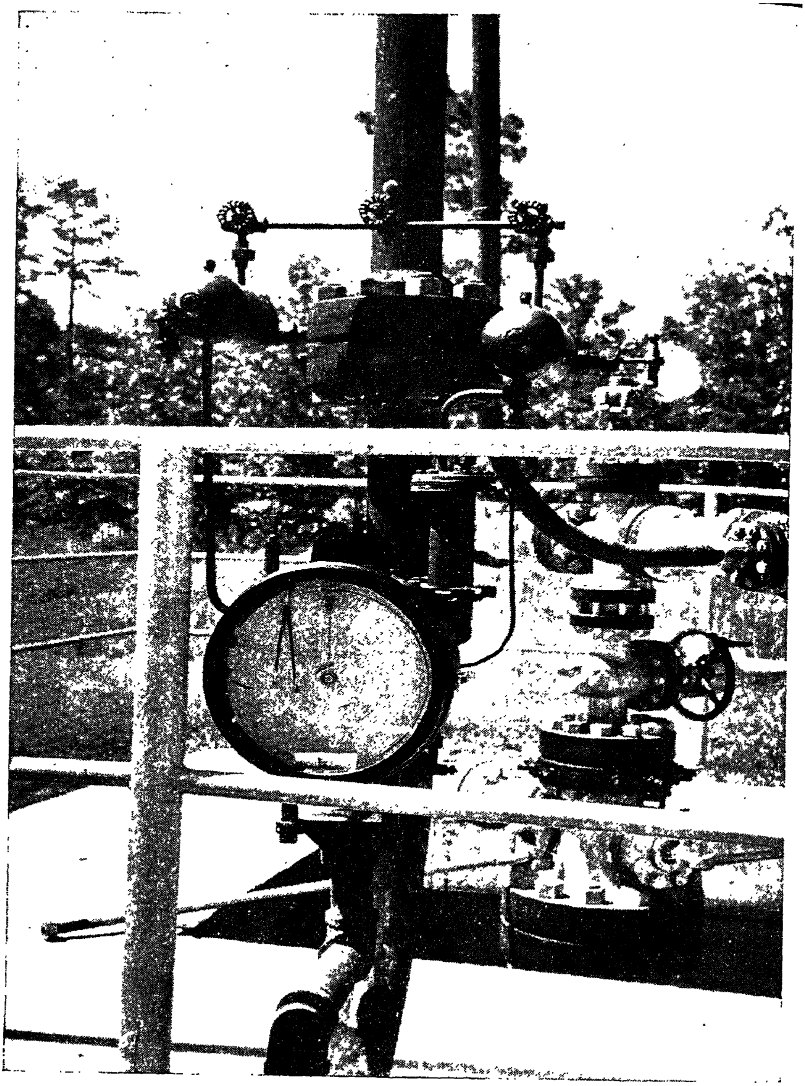

Fig. 8743
Foxboro Flow Meter on a recycling well, Louisiana

FOXBORO FLOW CURVE FOR GASES

20 INCH DIFFERENTIAL

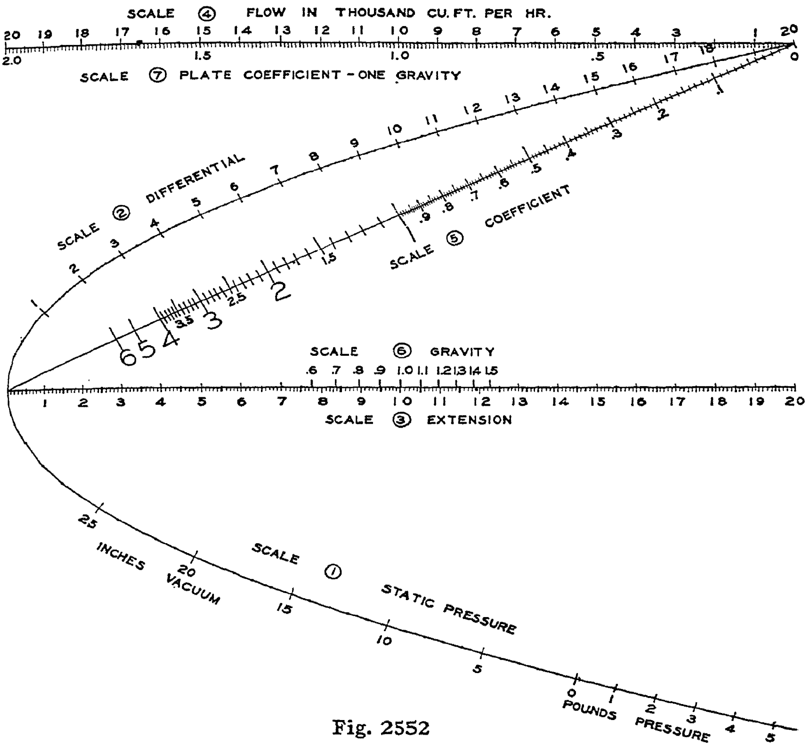

Fig. 2552

Directions for Using Flow-Curve for Gases

To determine the size of Orifice to give a certain Differential at a given Flow, Static Pressure and Gravity:

1. With a straight edge set the Static Pressure on scale 1, Differential on scale 2, and read Extension on scale 3.

2. Keep setting on scale 3 and set the flow on scale 4 and read scale 5, which is the corrected coefficient.

3. Keep setting on scale 5 and set Gravity on scale 6 and read the Coefficient for Gravity of 1 on scale 7. This value referred to the Table of Coefficients* gives the proper size Orifice.

*Table XVIII, pages 94 and 95, for flange, and Table XX, pages 96 and 97, for pipe connections.

FOXBORO FLOW CURVE FOR GASES

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50 INCH AND 100 INCH DIFFERENTIAL

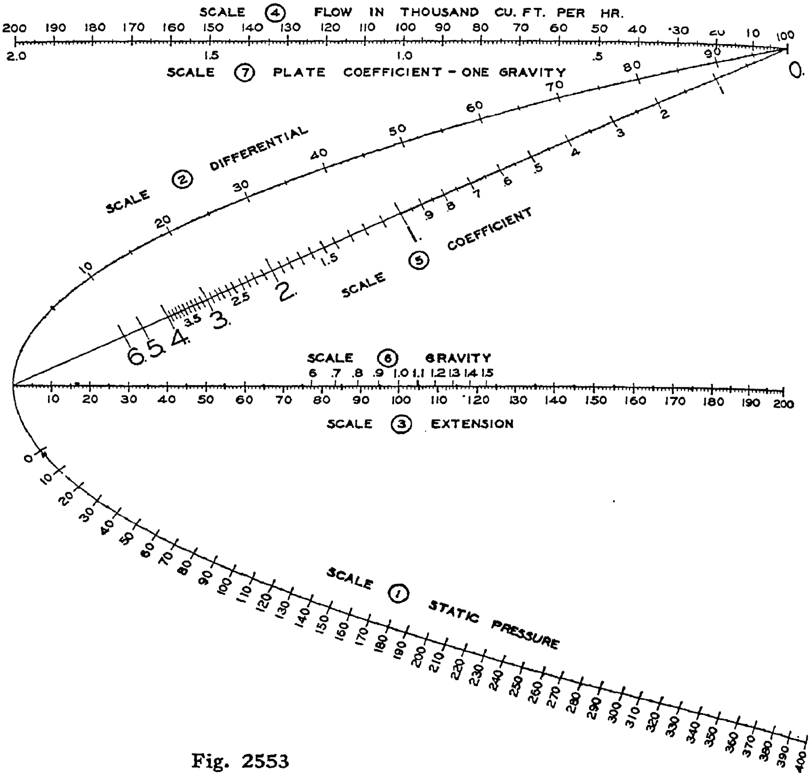

Fig. 2553

NOTE: All flows should be reduced to thousand cubic feet per hour.

To determine flow through certain size plate.

1. Set on scales 1 and 2 and read scale 3.
2. Set reading on scale 3 and Coefficient* in thousand cubic feet on scale 5 and read flow on scale 4.
3. Correct this for Gravity by setting on scale 6 and read scale 5 in hundred thousand cubic feet per hour.

*Table XVIII, pages 94 and 95, for flange, and Table XX, pages 96 and 97, for pipe connections.

Computing Orifice Sizes to Give Even Coefficients

It is often desired to use orifice plates of such size that the coefficients will be in round numbers, such as 1000, 2000, 3000, etc. cu. ft. per hour. This coefficient multiplied by the extension, square root of h × P, will give the flow for the hourly period.

In order to accomplish this, solve for the value of S in the following formula:

$$S = \frac{C}{KD^2F_{gp}F_tF_{tb}F_{pv}F_m} \quad \text{. . . . . } \textit{Equation 63}$$

Look up this value of S (in the table of S_f, if using flange connections, or in the table of S_p, if using pipe connections) and find the corresponding value of d/D. It will be necessary to interpolate if more than three places are desired in the answer. A column showing differences between the successive values of S is provided for convenience in performing this interpolation. Having determined the value of d/D, multiply this by D to obtain the value of d. The product is the desired orifice size.

Example

(Flange Taps)

Line Size 12″
Coeff. 15,000 cu. ft./hr.
Sp. Gr. .6
Flow. Temp. 60°F.
Press. Base 14.4
$F_{pv} = 1.0$
$F_m = 1.0$

$$S_f = \frac{15000}{345.92 \times 12^2 \times 1.291 \times 1 \times 1}$$

$$S_f = .23325 \qquad \frac{d}{D} = .59878 \qquad d = 7.185''$$

(Pipe Taps)

Line Size 12″
Coeff. 15,000 cu. ft./hr.
Sp. Gr. .6
Flow. Temp. 60°F.
Press. Base 14.4
$F_{pv} = 1.0$
$F_m = 1.0$

$$S_p = \frac{15000}{345.755 \times 12^2 \times 1.291 \times 1 \times 1}$$

$$S_p = .23336 \qquad \frac{d}{D} = .54754 \qquad d = 6.570''$$

Computing Orifice Sizes for Direct-Reading Meters

Often the static pressure is constant, or practically so, for a given installation. In such cases it will be possible to compute an orifice size which will make the differential pen direct reading on a direct-reading chart. In order to determine the correct orifice size, solve for S in the following equation:

$$\mathbf{S} = \frac{\mathbf{Q_m}}{\mathbf{KD^2F_{gp}F_tF_{tb}F_{pv}F_m\sqrt{h_mP}}} \quad \ldots\ldots\ldots \quad \textit{Equation 64}$$

Look up the resulting value of S (in the table for S_f, if using flange connections, or in the table for S_p, if using pipe connections), and note the corresponding value of d/D. It will be necessary to interpolate if more than three places are desired in the result.

Having found the value of d/D, multiply by D, in order to obtain d. The product will be the correct size orifice.

Example

(Flange Taps)

Line Size 12″

Max. Flow 1,500,000 cu. ft./hr.

Sp. Gr. .6

Flow. Temp. 60°F.

hm 100″

Press. Base 14.4 lbs.

Press. (abs.) 85 + 14.4 = 99.4 lbs.

F_{pv} = 1.006

F_m = 1.0

$$S_f = \frac{1,500,000}{345.92\times 12^2\times 1.291\times 1\times 1\times 1.006\times\sqrt{100}\times\sqrt{99.4}}$$

$S_f = .23256 \qquad \frac{d}{D} = .5981 \qquad d = 7.177''$

(Pipe Taps)

Line Size 12″

Max. Flow 1,500,000 cu. ft./hr.

Sp. Gr. .6

Flow. Temp. 60°F.

hm 100″

Press. Base 14.4 lbs.

Press. (abs.) 85 + 14.4 = 99.4 lbs.

F_{pv} = 1.006

F_m = 1.000

$$S_p = \frac{1,500,000}{345.755\times 12^2\times 1.291\times 1\times 1\times 1.006\times\sqrt{100}\times\sqrt{99.4}}$$

$S_p = .23267 \qquad \frac{d}{D} = 5.460 \qquad d = 6.552''$

0–10 SQUARE ROOT CHARTS

As the 0–10 square root chart is commonly used in gas measurement, the pens record the square root of the percentage which static and differential reading represent of full-scale value. At full-scale deflection the reading on the chart is the square root of 100; that is, 10. At one per cent of maximum readable differential or static, the reading is 1. Suppose instrument range were 0–50″ 0–250 lbs.; the reading of one on the square root chart would correspond to 0.5″ differential or 2.5 lbs. pressure. These values are 1% of the instrument range.

In using the square root chart in gas measurement, the static pen is set to read zero when subjected to absolute vacuum. This may be accomplished by use of a test chart divided in pounds per square inch or inches of mercury.* The chart used is the same range as the static tube. Corresponding readings are then taken on a test gauge and on the test chart. The micrometer is then adjusted until the static pen of the recorder reads high (with respect to the test gauge) by the amount of barometric pressure. The test chart is then removed and replaced by the 0–10 square root chart. The instrument now reads square root of per cent of full-scale absolute pressure reading.

The unit coefficient, C_u, for a square root chart, is the figure which, multiplied by the reading of the differential pen times the reading of the static pen, gives rate of flow in cubic feet per hour. For an orifice, the coefficient of which is already known, it may be computed from the following formula: $C_u = .01\sqrt{h_m P_m}\,C$ in which C is the coefficient, which may be obtained by multiplying the basic coefficient (from tables) by the various correction factors for flowing temperature, gravity, pressure base, and temperature base.

*When test chart is not available, setting on square root chart may be determined from the formula—

$$\text{Setting} \quad \sqrt{\frac{\text{Barometric pressure} \times 100}{\text{Static Range}}}$$

TO COMPUTE AN EVEN COEFFICIENT FOR 0-10 SQUARE ROOT CHARTS

For convenience in computing 0–10 square root chart records, and for facilitating mental calculations of hourly send-outs, it is often desirable so to regulate the size of orifice that the unit coefficient will be expressed in round numbers, such as 1000, 10,000, 20,000, etc. A great deal of confusion is avoided if orifice calculations are based on full-capacity readings. This may be accomplished in the following manner:

Considering the static and differential pens both to be at full scale reading, the multiplier for the 0–10 square root chart will be 100. The flow will be 100 C_u. This flow may also be expressed as:

$$KSD^2F_{gp}\,F_t\,F_{tb}\,\sqrt{h_m\,P_m} = Q_m = 100\,C_u$$

$$S = \frac{100\,C_u}{KD^2F_{gp}F_tF_{tb}F_{pv}F_m\sqrt{h_mP_m}} \quad . \; . \; . \; . \; . \; . \; . \; . \; \textit{Equation 65}$$

h_m = differential range of instrument (100″ — 60″ — 50″ — 20″).

P_m = gauge pressure range of instrument + barometric pressure.*

$\sqrt{h_m\,P_m}$ may be obtained from an extension table or may be computed.

K = constant = 345.92 for flange taps = 345.755 for pipe taps. (This difference is due to a discrepancy in the value for acceleration of gravity used in the derivation of the coefficients.)

Solve for the value of S and interpolate from the tables to obtain $\frac{d}{D}$

Multiply $\frac{d}{D}$ by D to obtain orifice size.

* NOTE: When using the 0–10 square root chart, the static pen is set so it would read zero at absolute vacuum. Hence P_m is the same as the pressure range of the spring (i.e., 100 lbs. 500 lbs., etc.).

Example Showing Computation of Orifice

Line Size = 12″.

Maximum readable flow desired = Q_m = 1,500,000 cu. ft./hr.

$C_u = \frac{Q_m}{100}$ = 15,000 cu. ft./hr.

Sp. Gr. = .6.

Pressure base = 14.4 pounds per sq. in. absolute.

Flowing Temperature = 60° F.

Differential range = h_m = 100″.

Absolute static range = P_m = 250 lbs.

Operating pressure = 175 lbs.

F_{pv} = 1.012.

F_m = 1.0.

Flange Taps

$$S_f = \frac{100C_u}{345.92\ D^2\ F_{gp}\ F_t\ F_{tb}\sqrt{h_m P_m}}$$

$$\frac{100 \times 15{,}000}{345.92 \times 12^2 \times 1.291 \times 1 \times 1.012\sqrt{100 \times 250}} = .14577$$

$\frac{d}{D}$ from Table XXV = .4875 d = 12″ × .4875 = 5.850″

Pipe Taps

Take the same data as above.

$$S_p = \frac{100 \times 15{,}000}{345.755 \times 12^2 \times 1.291 \times 1 \times 1.012\sqrt{100 \times 250}} \quad .14584$$

$\frac{d}{D}$ from Table XXVI = .4542 d = 12 × .4542 = 5.450″

DETERMINING CORRECT FLOW CAPACITY

The problem as it presents itself in the field is first one of choosing a correct capacity which will give legible readings under the conditions existing at the installation. Knowing maximum rate of flow and average static pressure, it is desired to choose a capacity which will give a legible reading on the differential pen. For instance, on a 0–100″ meter, a reading of 80″ at maximum flow should be satisfactory.

Use the following formula to obtain the desired flow capacity:

$$\text{Flow capacity} > \sqrt{\frac{h_m\ P_m}{\text{Average absolute static} \times \text{desired differential}}} \times \text{max. flow}$$

Example Showing Method of Choosing Flow Capacity

Range 0–100″ 0–250 lbs.

Average gauge pressure = 190 lbs. = 204.4 lbs. absolute.

Desired differential = 80″.

Maximum flow = 1,200,000 cu. ft. per hr.

$$\text{Flow capacity} > \sqrt{\frac{100 \times 250}{80 \times 204.4}} \times 1{,}200{,}000 \text{ cu. ft. per hr.}$$

$$= 1{,}484{,}000 \text{ cu. ft./hr.}$$

Next larger even number = 1,500,000 cu. ft./hr.

TABLE XXV
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.010	.000061	.000012	.050	.001515	.000061
.011	.000073	.000014	.051	.001576	.000063
.012	.000087	.000015	.052	.001639	.000063
.013	.000102	.000017	.053	.001702	.000065
.014	.000119	.000017	.054	.001767	.000066
.015	.000136	.000019	.055	.001833	.000067
.016	.000155	.000020	.056	.001900	.000069
.017	.000175	.000021	.057	.001969	.000070
.018	.000196	.000023	.058	.002039	.000070
.019	.000219	.000023	.059	.002109	.000073
.020	.000242	.000025	.060	.002182	.000073
.021	.000267	.000026	.061	.002255	.000074
.022	.000293	.000028	.062	.002329	.000076
.023	.000321	.000028	.063	.002405	.000077
.024	.000349	.000030	.064	.002482	.000078
.025	.000379	.000031	.065	.002560	.000080
.026	.000410	.000032	.066	.002640	.000080
.027	.000442	.000033	.067	.002720	.000082
.028	.000475	.000035	.068	.002802	.000083
.029	.000510	.000035	.069	.002885	.000084
.030	.000545	.000037	.070	.002969	.000086
.031	.000582	.000039	.071	.003055	.000087
.032	.000621	.000039	.072	.003142	.000087
.033	.000660	.000041	.073	.003229	.000089
.034	.000701	.000041	.074	.003318	.000091
.035	.000742	.000043	.075	.003409	.000091
.036	.000785	.000045	.076	.003500	.000093
.037	.000830	.000045	.077	.003593	.000094
.038	.000875	.000047	.078	.003687	.000095
.039	.000922	.000048	.079	.003782	.000096
.040	.000970	.000049	.080	.003878	.000098
.041	.001019	.000050	.081	.003976	.000099
.042	.001069	.000051	.082	.004075	.000100
.043	.001120	.000053	.083	.004175	.000101
.044	.001173	.000054	.084	.004276	.000102
.045	.001227	.000055	.085	.004378	.000104
.046	.001282	.000057	.086	.004482	.000105
.047	.001339	.000057	.087	.004587	.000106
.048	.001396	.000059	.088	.004693	.000107
.049	.001455	.000060	.089	.004800	.000109

TABLE XXV — *Continued*

S VALUES

FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.090	.004909	.000109	.130	.010241	.000159
.091	.005018	.000111	.131	.010400	.000159
.092	.005129	.000112	.132	.010559	.000161
.093	.005241	.000114	.133	.010720	.000161
.094	.005355	.000114	.134	.010881	.000163
.095	.005469	.000116	.135	.011044	.000165
.096	.005585	.000117	.136	.011209	.000165
.097	.005702	.000118	.137	.011374	.000167
.098	.005820	.000119	.138	.011541	.000168
.099	.005939	.000121	.139	.011709	.000169
.100	.006060	.000122	.140	.011878	.000170
.101	.006182	.000123	.141	.012048	.000171
.102	.006305	.000124	.142	.012219	.000173
.103	.006429	.000125	.143	.012392	.000174
.104	.006554	.000127	.144	.012566	.000175
.105	.006681	.000128	.145	.012741	.000176
.106	.006809	.000129	.146	.012917	.000178
.107	.006938	.000130	.147	.013095	.000179
.108	.007068	.000132	.148	.013274	.000180
.109	.007200	.000133	.149	.013454	.000181
.110	.007333	.000134	.150	.013635	.000182
.111	.007467	.000135	.151	.013817	.000184
.112	.007602	.000136	.152	.014001	.000185
.113	.007738	.000138	.153	.014186	.000186
.114	.007876	.000138	.154	.014372	.000187
.115	.008014	.000140	.155	.014559	.000189
.116	.008154	.000142	.156	.014748	.000189
.117	.008296	.000142	.157	.014937	.000191
.118	.008438	.000144	.158	.015128	.000192
.119	.008582	.000144	.159	.015320	.000194
.120	.008726	.000146	.160	.015514	.000194
.121	.008872	.000148	.161	.015708	.000196
.122	.009020	.000148	.162	.015904	.000197
.123	.009168	.000150	.163	.016101	.000198
.124	.009318	.000151	.164	.016299	.000199
.125	.009469	.000152	.165	.016498	.000201
.126	.009621	.000153	.166	.016699	.000202
.127	.009774	.000155	.167	.016901	.000203
.128	.009929	.000155	.168	.017104	.000204
.129	.010084	.000157	.169	.017308	.000205

Continued on page [illegible]

TABLE XXV—*Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.170	.017513	.000207	.210	.026725	.000255
.171	.017720	.000208	.211	.026980	.000256
.172	.017928	.000209	.212	.027236	.000258
.173	.018137	.000210	.213	.027494	.000258
.174	.018347	.000212	.214	.027752	.000260
.175	.018559	.000212	.215	.028012	.000262
.176	.018771	.000214	.216	.028274	.000262
.177	.018985	.000216	.217	.028536	.000264
.178	.019201	.000216	.218	.028800	.000264
.179	.019417	.000217	.219	.029064	.000266
.180	.019634	.000219	.220	.029330	.000268
.181	.019853	.000220	.221	.029598	.000268
.182	.020073	.000221	.222	.029866	.000270
.183	.020294	.000223	.223	.030136	.000271
.184	.020517	.000223	.224	.030407	.000272
.185	.020740	.000225	.225	.030679	.000273
.186	.020965	.000226	.226	.030952	.000275
.187	.021191	.000227	.227	.031227	.000275
.188	.021418	.000229	.228	.031502	.000277
.189	.021647	.000230	.229	.031779	.000278
.190	.021877	.000230	.230	.032057	.000280
.191	.022107	.000233	.231	.032337	.000280
.192	.022340	.000233	.232	.032617	.000282
.193	.022573	.000234	.233	.032899	.000283
.194	.022807	.000236	.234	.033182	.000284
.195	.023043	.000237	.235	.033466	.000286
.196	.023280	.000238	.236	.033752	.000286
.197	.023518	.000240	.237	.034038	.000288
.198	.023758	.000240	.238	.034326	.000289
.199	.023998	.000242	.239	.034615	.000291
.200	.024240	.000243	.240	.034906	.000291
.201	.024483	.000244	.241	.035197	.000293
.202	.024727	.000246	.242	.035490	.000294
.203	.024973	.000246	.243	.035784	.000295
.204	.025219	.000248	.244	.036079	.000296
.205	.025467	.000249	.245	.036375	.000298
.206	.025716	.000250	.246	.036673	.000298
.207	.025966	.000253	.247	.036971	.000300
.208	.026218	.000253	.248	.037271	.000302
.209	.026471	.000254	.249	.037573	.000302

Continued on page 118

TABLE XXV — *Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.250	.037875	.000304	.290	.050965	.000352
.251	.038179	.000304	.291	.051317	.000353
.252	.038483	.000306	.292	.051670	.000354
.253	.038789	.000308	.293	.052024	.000356
.254	.039097	.000308	.294	.052380	.000357
.255	.039405	.000310	.295	.052737	.000358
.256	.039715	.000311	.296	.053095	.000360
.257	.040026	.000312	297	.053455	.000360
.258	.040338	.000313	.298	.053815	.000362
.259	.040651	.000315	.299	.054177	.000363
.260	.040966	.000315	.300	.054540	.000364
.261	.041281	.000317	.301	.054904	.000366
.262	.041598	.000318	.302	.055270	.000366
.263	.041916	.000320	.303	.055636	.000368
.264	.042236	.000320	.304	.056004	.000369
.265	.042556	.000322	.305	.056373	.000370
.266	.042878	.000323	.306	.056743	.000372
.267	.043201	.000324	.307	.057115	.000373
.268	.043525	.000326	.308	.057488	.000374
.269	.043851	.000326	.309	.057862	.000375
.270	.044177	.000328	.310	.058237	.000376
.271	.044505	.000329	.311	.058613	.000377
.272	.044834	.000331	.312	.058990	.000379
.273	.045165	.000331	.313	.059369	.000380
.274	.045496	.000333	.314	.059749	.000381
.275	.045829	.000334	.315	.060130	.000383
.276	.046163	.000335	.316	.060513	.000383
.277	.046498	.000336	.317	.060896	.000385
.278	.046834	.000338	.318	.061281	.000386
.279	.047172	.000338	.319	.061667	.000387
.280	.047510	.000340	.320	.062054	.000389
.281	.047850	.000342	.321	.062443	.000390
.282	.048192	.000342	.322	.062833	.000390
.283	.048534	.000344	.323	.063223	.000392
.284	.048878	.000344	.324	.063615	.000394
.285	.049222	.000346	.325	.064009	.000394
.286	.049568	.000348	.326	.064403	.000396
.287	.049916	.000348	.327	.064799	.000397
.288	.050264	.000350	.328	.065196	.000398
.289	.050614	.000351	.329	.065594	.000399

Continued on page 119

Report No. 1

Table XXV — *Continued*
S Values
For Flange Connections

$$S = \frac{Ed^2}{D^2}$$

d/D	S	Diff.	d/D	S	Diff.
.330	.065993	.000401	.370	.082961	.000449
.331	.066394	.000402	.371	.083410	.000451
.332	.066796	.000403	.372	.083861	.000451
.333	.067199	.000404	.373	.084312	.000453
.334	.067603	.000405	.374	.084765	.000454
.335	.068008	.000407	.375	.085219	.000455
.336	.068415	.000408	.376	.085674	.000456
.337	.068823	.000409	.377	.086130	.000458
.338	.069232	.000410	.378	.086588	.000458
.339	.069642	.000412	.379	.087046	.000460
.340	.070054	.000412	.380	.087506	.000462
.341	.070466	.000414	.381	.087968	.000462
.342	.070880	.000415	.382	.088430	.000464
.343	.071295	.000417	.383	.088894	.000464
.344	.071712	.000417	.384	.089358	.000466
.345	.072129	.000419	.385	.089824	.000468
.346	.072548	.000420	.386	.090292	.000468
.347	.072968	.000421	.387	.090760	.000470
.348	.073389	.000422	.388	.091230	.000471
.349	.073811	.000424	.389	.091701	.000472
.350	.074235	.000425	.390	.092173	.000473
.351	.074660	.000426	.391	.092646	.000474
.352	.075086	.000427	.392	.093120	.000476
.353	.075513	.000428	.393	.093596	.000477
.354	.075941	.000430	.394	.094073	.000478
.355	.076371	.000431	.395	.094551	.000479
.356	.076802	.000432	.396	.095030	.000481
.357	.077234	.000433	.397	.095511	.000482
.358	.077667	.000435	.398	.095993	.000483
.359	.078102	.000436	.399	.096476	.000484
.360	.078538	.000437	.400	.096960	.000485
.361	.078975	.000438	.401	.097445	.000487
.362	.079413	.000439	.402	.097932	.000488
.363	.079852	.000441	.403	.098420	.000489
.364	.080293	.000441	.404	.098909	.000490
.365	.080734	.000443	.405	.099399	.000492
.366	.081177	.000445	.406	.099891	.000492
.367	.081622	.000445	.407	.100383	.000494
.368	.082067	.000447	.408	.100877	.000495
.369	.082514	.000447	.409	.101372	.000497

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TABLE XXV — *Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.410	.101869	.000497	.450	.123120	.000568
.411	.102366	.000500	.451	.123688	.000571
.412	.102866	.000501	.452	.124259	.000572
.413	.103367	.000502	.453	.124831	.000574
.414	.103869	.000505	.454	.125405	.000576
.415	.104374	.000506	.455	.125981	.000578
.416	.104880	.000507	.456	.126559	.000580
.417	.105387	.000510	.457	.127139	.000582
.418	.105897	.000511	.458	.127721	.000584
.419	.106408	.000512	.459	.128305	.000586
.420	.106920	.000515	.460	.128891	.000588
.421	.107435	.000516	.461	.129479	.000590
.422	.107951	.000518	.462	.130069	.000591
.423	.108469	.000519	.463	.130660	.000594
.424	.108988	.000522	.464	.131254	.000596
.425	.109510	.000523	.465	.131850	.000598
.426	.110033	.000524	.466	.132448	.000600
.427	.110557	.000527	.467	.133048	.000602
.428	.111084	.000528	.468	.133650	.000603
.429	.111612	.000530	.469	.134253	.000606
.430	.112142	.000532	.470	.134859	.000608
.431	.112674	.000533	.471	.135467	.000611
.432	.113207	.000535	.472	.136078	.000612
.433	.113742	.000537	.473	.136690	.000614
.434	.114279	.000539	.474	.137304	.000616
.435	.114818	.000541	.475	.137920	.000619
.436	.115359	.000542	.476	.138539	.000620
.437	.115901	.000544	.477	.139159	.000623
.438	.116445	.000546	.478	.139782	.000625
.439	.116991	.000548	.479	.140407	.000627
.440	.117539	.000550	.480	.141034	.000629
.441	.118089	.000552	.481	.141663	.000631
.442	.118641	.000553	.482	.142294	.000633
.443	.119194	.000555	.483	.142927	.000636
.444	.119749	.000557	.484	.143563	.000637
.445	.120306	.000559	.485	.144200	.000640
.446	.120865	.000561	.486	.144840	.000642
.447	.121426	.000563	.487	.145482	.000644
.448	.121989	.000564	.488	.146126	.000647
.449	.122553	.000567	.489	.146773	.000648

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TABLE XXV—*Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.490	.147421	.000651	.530	.175282	.000747
.491	.148072	.000653	.531	.176029	.000749
.492	.148725	.000656	.532	.176778	.000752
.493	.149381	.000657	.533	.177530	.000755
.494	.150038	.000660	.534	.178285	.000758
.495	.150698	.000662	.535	.179043	.000760
.496	.151360	.000664	.536	.179803	.000762
.497	.152024	.000667	.537	.180565	.000766
.498	.152691	.000669	.538	.181331	.000768
.499	.153360	.000671	.539	.182099	.000771
.500	.154031	.000674	.540	.182870	.000773
.501	.154705	.000676	.541	.183643	.000776
.502	.155381	.000678	.542	.184419	.000779
.503	.156059	.000680	.543	.185198	.000781
.504	.156739	.000683	.544	.185979	.000785
.505	.157422	.000685	.545	.186764	.000787
.506	.158107	.000688	.546	.187551	.000789
.507	.158795	.000690	.547	.188340	.000793
.508	.159485	.000692	.548	.189133	.000795
.509	.160177	.000695	.549	.189928	.000798
.510	.160872	.000697	.550	.190726	.000801
.511	.161569	.000699	.551	.191527	.000804
.512	.162268	.000702	.552	.192331	.000806
.513	.162970	.000705	.553	.193137	.000809
.514	.163675	.000706	.554	.193946	.000812
.515	.164381	.000710	.555	.194758	.000815
.516	.165091	.000711	.556	.195573	.000818
.517	.165802	.000715	.557	.196391	.000821
.518	.166517	.000716	.558	.197212	.000823
.519	.167233	.000719	.559	.198035	.000827
.520	.167952	.000722	.560	.198862	.000829
.521	.168674	.000724	.561	.199691	.000832
.522	.169398	.000726	.562	.200523	.000835
.523	.170124	.000730	.563	.201358	.000838
.524	.170854	.000731	.564	.202196	.000841
.525	.171585	.000734	.565	.203037	.000844
.526	.172319	.000737	.566	.203881	.000847
.527	.173056	.000739	.567	.204728	.000850
.528	.173795	.000742	.568	.205578	.000852
.529	.174537	.000745	.569	.206430	.000856

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TABLE XXV — *Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.570	.207286	.000859	.610	.244098	.000988
.571	.208145	.000862	.611	.245086	.000991
.572	.209007	.000865	.612	.246077	.000995
.573	.209872	.000867	.613	.247072	.000999
.574	.210739	.000871	.614	.248071	.001002
.575	.211610	.000874	.615	.249073	.001006
.576	.212484	.000877	.616	.250079	.001009
.577	.213361	.000880	.617	.251088	.001012
.578	.214241	.000883	.618	.252100	.001017
.579	.215124	.000887	.619	.253117	.001019
.580	.216011	.000889	.620	.254136	.001024
.581	.216900	.000893	.621	.255160	.001027
.582	.217793	.000895	.622	.256187	.001030
.583	.218688	.000899	.623	.257217	.001035
.584	.219587	.000902	.624	.258252	.001037
.585	.220489	.000905	.625	.259289	.001042
.586	.221394	.000908	.626	.260331	.001045
.587	.222302	.000912	.627	.261376	.001049
.588	.223214	.000915	.628	.262425	.001053
.589	.224129	.000918	.629	.263478	.001056
.590	.225047	.000921	.630	.264534	.001060
.591	.225968	.000924	.631	.265594	.001063
.592	.226892	.000928	.632	.266657	.001068
.593	.227820	.000931	.633	.267725	.001071
.594	.228751	.000934	.634	.268796	.001075
.595	.229685	.000937	.635	.269871	.001079
.596	.230622	.000941	.636	.270950	.001082
.597	.231563	.000944	.637	.272032	.001086
.598	.232507	.000947	.638	.273118	.001090
.599	.233454	.000951	.639	.274208	.001094
.600	.234405	.000954	.640	.275302	.001098
.601	.235359	.000957	.641	.276400	.001102
.602	.236316	.000961	.642	.277502	.001105
.603	.237277	.000964	.643	.278607	.001110
.604	.238241	.000968	.644	.279717	.001113
.605	.239209	.000971	.645	.280830	.001117
.606	.240180	.000974	.646	.281947	.001121
.607	.241154	.000978	.647	.283068	.001125
.608	.242132	.000981	.648	.284193	.001129
.609	.243113	.000985	.649	.285322	.001133

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Table XXV — *Continued*
S Values
For Flange Connections

$$S = \frac{Ed^2}{D^2}$$

d/D	S	Diff.	d/D	S	Diff.
.650	.286455	.001137	.690	.335174	.001307
.651	.287592	.001141	.691	.336481	.001312
.652	.288733	.001145	.692	.337793	.001316
.653	.289878	.001149	.693	.339109	.001321
.654	.291027	.001152	.694	.340430	.001325
.655	.292179	.001157	.695	.341755	.001330
.656	.293336	.001161	.696	.343085	.001335
.657	.294497	.001165	.697	.344420	.001339
.658	.295662	.001169	.698	.345759	.001344
.659	.296831	.001174	.699	.347103	.001348
.660	.298005	.001177	.700	.348451	.001353
.661	.299182	.001182	.701	.349804	.001358
.662	.300364	.001185	.702	.351162	.001363
.663	.301549	.001190	.703	.352525	.001367
.664	.302739	.001194	.704	.353892	.001372
.665	.303933	.001198	.705	.355264	.001377
.666	.305131	.001202	.706	.356641	.001381
.667	.306333	.001207	.707	.358022	.001387
.668	.307540	.001210	.708	.359409	.001391
.669	.308750	.001215	.709	.360800	.001396
.670	.309965	.001220	.710	.362196	.001400
.671	.311185	.001223	.711	.363596	.001406
.672	.312408	.001228	.712	.365002	.001411
.673	.313636	.001232	.713	.366413	.001415
.674	.314868	.001236	.714	.367828	.001420
.675	.316104	.001241	.715	.369248	.001425
.676	.317345	.001245	.716	.370673	.001430
.677	.318590	.001249	.717	.372103	.001435
.678	.319839	.001253	.718	.373538	.001440
.679	.321092	.001259	.719	.374978	.001445
.680	.322351	.001262	.720	.376423	.001450
.681	.323613	.001267	.721	.377873	.001455
.682	.324880	.001271	.722	.379328	.001460
.683	.326151	.001276	.723	.380788	.001465
.684	.327427	.001280	.724	.382253	.001470
.685	.328707	.001284	.725	.383723	.001475
.686	.329991	.001289	.726	.385198	.001480
.687	.331280	.001294	.727	.386678	.001485
.688	.332574	.001298	.728	.388163	.001490
.689	.333872	.001302	.729	.389653	.001496

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TABLE XXV — *Continued*
S VALUES
FOR FLANGE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.730	.391149	.001500	.740	.406388	.001552
.731	.392649	.001506	.741	.407940	.001558
.732	.394155	.001511	.742	.409498	.001564
.733	.395666	.001516	.743	.411062	.001569
.734	.397182	.001521	.744	.412631	.001574
.735	.398703	.001526	.745	.414205	.001579
.736	.400229	.001532	.746	.415784	.001585
.737	.401761	.001537	.747	.417369	.001590
.738	.403298	.001542	.748	.418959	.001596
.739	.404840	.001548	.749	.420555	.001601
			.750	.422156	.001601

Table XXVI
S Values
For Pipe Connections

$$S = \frac{Ed^2}{D^2}$$

d/D	S	Diff.	d/D	S	Diff.
.010	.000059	.000013	.050	.001503	.000061
.011	.000072	.000013	.051	.001564	.000062
.012	.000085	.000015	.052	.001626	.000064
.013	.000100	.000016	.053	.001690	.000065
.014	.000116	.000017	.054	.001755	.000066
.015	.000133	.000019	.055	.001821	.000068
.016	.000152	.000020	.056	.001889	.000068
.017	.000172	.000020	.057	.001957	.000070
.018	.000192	.000022	.058	.002027	.000071
.019	.000214	.000024	.059	.002098	.000073
.020	.000238	.000024	.060	.002171	.000074
.021	.000262	.000026	.061	.002245	.000074
.022	.000288	.000027	.062	.002319	.000077
.023	.000315	.000028	.063	.002396	.000077
.024	.000343	.000029	.064	.002473	.000079
.025	.000372	.000031	.065	.002552	.000081
.026	.000403	.000032	.066	.002633	.000080
.027	.000435	.000033	.067	.002713	.000082
.028	.000468	.000034	.068	.002795	.000084
.029	.000502	.000035	.069	.002879	.000085
.030	.000537	.000037	.070	.002964	.000086
.031	.000574	.000038	.071	.003050	.000088
.032	.000612	.000039	.072	.003138	.000088
.033	.000651	.000040	.073	.003226	.000090
.034	.000691	.000041	.074	.003316	.000092
.035	.000732	.000043	.075	.003408	.000092
.036	.000775	.000044	.076	.003500	.000094
.037	.000819	.000045	.077	.003594	.000095
.038	.000864	.000047	.078	.003689	.000096
.039	.000911	.000047	.079	.003785	.000098
.040	.000958	.000049	.080	.003883	.000098
.041	.001007	.000050	.081	.003981	.000100
.042	.001057	.000052	.082	.004081	.000102
.043	.001109	.000052	.083	.004183	.000102
.044	.001161	.000054	.084	.004285	.000104
.045	.001215	.000055	.085	.004389	.000106
.046	.001270	.000056	.086	.004495	.000106
.047	.001326	.000058	.087	.004601	.000108
.048	.001384	.000059	.088	.004709	.000109
.049	.001443	.000060	.089	.004818	.000110

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TABLE XXVI—*Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.090	.004928	.000111	.130	.010387	.000162
.091	.005039	.000113	.131	.010549	.000165
.092	.005152	.000114	.132	.010714	.000165
.093	.005266	.000115	.133	.010879	.000167
.094	.005381	.000117	.134	.011046	.000168
.095	.005498	.000118	.135	.011214	.000170
.096	.005616	.000119	.136	.011384	.000170
.097	.005735	.000120	.137	.011554	.000172
.098	.005855	.000122	.138	.011726	.000174
.099	.005977	.000123	.139	.011900	.000174
.100	.006100	.000124	.140	.012074	.000176
.101	.006224	.000126	.141	.012250	.000177
.102	.006350	.000127	.142	.012427	.000179
.103	.006477	.000128	.143	.012606	.000180
.104	.006605	.000129	.144	.012786	.000181
.105	.006734	.000131	.145	.012967	.000183
.106	.006865	.000132	.146	.013150	.000184
.107	.006997	.000133	.147	.013334	.000184
.108	.007130	.000134	.148	.013518	.000187
.109	.007264	.000136	.149	.013705	.000188
.110	.007400	.000137	.150	.013893	.000189
.111	.007537	.000138	.151	.014082	.000191
.112	.007675	.000140	.152	.014273	.000191
.113	.007815	.000141	.153	.014464	.000193
.114	.007956	.000142	.154	.014657	.000195
.115	.008098	.000144	.155	.014852	.000196
.116	.008242	.000144	.156	.015048	.000197
.117	.008386	.000147	.157	.015245	.000198
.118	.008533	.000147	.158	.015443	.000200
.119	.008680	.000149	.159	.015643	.000201
.120	.008829	.000150	.160	.015844	.000202
.121	.008979	.000151	.161	.016046	.000204
.122	.009130	.000152	.162	.016250	.000205
.123	.009282	.000154	.163	.016455	.000206
.124	.009436	.000155	.164	.016661	.000208
.125	.009591	.000157	.165	.016869	.000209
.126	.009748	.000157	.166	.017078	.000210
.127	.009905	.000160	.167	.017288	.000212
.128	.010065	.000160	.168	.017500	.000213
.129	.010225	.000162	.169	.017713	.000215

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Table XXVI — *Continued*
S Values
For Pipe Connections

$$S = \frac{Ed^2}{D^2}$$

d/D	S	Diff.	d/D	S	Diff.
.170	.017928	.000215	.210	.027620	.000270
.171	.018143	.000217	.211	.027890	.000273
.172	.018360	.000219	.212	.028163	.000273
.173	.018579	.000220	.213	.028436	.000275
.174	.018799	.000221	.214	.028711	.000276
.175	.019020	.000222	.215	.028987	.000278
.176	.019242	.000224	.216	.029265	.000279
.177	.019466	.000225	.217	.029544	.000281
.178	.019691	.000227	.218	.029825	.000282
.179	.019918	.000228	.219	.030107	.000284
.180	.020146	.000229	.220	.030391	.000284
.181	.020375	.000230	.221	.030675	.000287
.182	.020605	.000232	.222	.030962	.000288
.183	.020837	.000234	.223	.031250	.000289
.184	.021071	.000234	.224	.031539	.000290
.185	.021305	.000236	.225	.031829	.000293
.186	.021541	.000238	.226	.032122	.000293
.187	.021779	.000239	.227	.032415	.000295
.188	.022018	.000240	.228	.032710	.000297
.189	.022258	.000241	.229	.033007	.000298
.190	.022499	.000243	.230	.033305	.000299
.191	.022742	.000244	.231	.033604	.000301
.192	.022986	.000246	.232	.033905	.000302
.193	.023232	.000247	.233	.034207	.000304
.194	.023479	.000248	.234	.034511	.000305
.195	.023727	.000250	.235	.034816	.000307
.196	.023977	.000251	.236	.035123	.000308
.197	.024228	.000253	.237	.035431	.000309
.198	.024481	.000254	.238	.035740	.000312
.199	.024735	.000255	.239	.036052	.000312
.200	.024990	.000257	.240	.036364	.000314
.201	.025247	.000258	.241	.036678	.000316
.202	.025505	.000259	.242	.036994	.000317
.203	.025764	.000261	.243	.037311	.000318
.204	.026025	.000262	.244	.037629	.000320
.205	.026287	.000264	.245	.037949	.000322
.206	.026551	.000265	.246	.038271	.000323
.207	.026816	.000267	.247	.038594	.000325
.208	.027083	.000268	.248	.038919	.000326
.209	.027351	.000269	.249	.039245	.000327

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TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.250	.039572	.000329	.290	.053956	.000393
.251	.039901	.000331	.291	.054349	.000394
.252	.040232	.000332	.292	.054743	.000397
.253	.040564	.000334	.293	.055140	.000397
.254	.040898	.000335	.294	.055537	.000400
.255	.041233	.000337	.295	.055937	.000401
.256	.041570	.000338	.296	.056338	.000403
.257	.041908	.000340	.297	.056741	.000405
.258	.042248	.000341	.298	.057146	.000406
.259	.042589	.000343	.299	.057552	.000408
.260	.042932	.000344	.300	.057960	.000410
.261	.043276	.000346	.301	.058370	.000411
.262	.043622	.000348	.302	.058781	.000413
.263	.043970	.000349	.303	.059194	.000415
.264	.044319	.000351	.304	.059609	.000417
.265	.044670	.000352	.305	.060026	.000419
.266	.045022	.000354	.306	.060445	.000420
.267	.045376	.000355	.307	.060865	.000422
.268	.045731	.000357	.308	.061287	.000424
.269	.046088	.000359	.309	.061711	.000425
.270	.046447	.000360	.310	.062136	.000427
.271	.046807	.000361	.311	.062563	.000429
.272	.047168	.000364	.312	.062992	.000431
.273	.047532	.000365	.313	.063423	.000433
.274	.047897	.000366	.314	.063856	.000434
.275	.048263	.000368	.315	.064290	.000437
.276	.048631	.000370	.316	.064727	.000438
.277	.049001	.000371	.317	.065165	.000439
.278	.049372	.000373	.318	.065604	.000442
.279	.049745	.000375	.319	.066046	.000444
.280	.050120	.000376	.320	.066490	.000445
.281	.050496	.000378	.321	.066935	.000447
.282	.050874	.000380	.322	.067382	.000449
.283	.051254	.000381	.323	.067831	.000451
.284	.051635	.000383	.324	.068282	.000453
.285	.052018	.000384	.325	.068735	.000455
.286	.052402	.000386	.326	.069190	.000456
.287	.052788	.000388	.327	.069646	.000459
.288	.053176	.000389	.328	.070105	.000460
.289	.053565	.000391	.329	.070565	.000462

Continued on page 129

TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.330	.071027	.000464	.370	.091145	.000546
.331	.071491	.000466	.371	.091691	.000548
.332	.071957	.000468	.372	.092239	.000550
.333	.072425	.000470	.373	.092789	.000552
.334	.072895	.000471	.374	.093341	.000555
.335	.073366	.000474	.375	.093896	.000557
.336	.073840	.000476	.376	.094453	.000560
.337	.074316	.000477	.377	.095013	.000561
.338	.074793	.000480	.378	.095574	.000564
.339	.075273	.000481	.379	.096138	.000566
.340	.075754	.000483	.380	.096704	.000569
.341	.076237	.000486	.381	.097273	.000570
.342	.076723	.000487	.382	.097843	.000573
.343	.077210	.000490	.383	.098416	.000575
.344	.077700	.000491	.384	.098991	.000578
.345	.078191	.000493	.385	.099569	.000580
.346	.078684	.000496	.386	.100149	.000582
.347	.079180	.000497	.387	.100731	.000585
.348	.079677	.000499	.388	.101316	.000587
.349	.080176	.000502	.389	.101903	.000590
.350	.080678	.000503	.390	.102493	.000591
.351	.081181	.000506	.391	.103084	.000595
.352	.081687	.000507	.392	.103679	.000596
.353	.082194	.000510	.393	.104275	.000599
.354	.082704	.000512	.394	.104874	.000602
.355	.083216	.000513	.395	.105476	.000604
.356	.083729	.000516	.396	.106080	.000606
.357	.084245	.000518	.397	.106686	.000609
.358	.084763	.000520	.398	.107295	.000611
.359	.085283	.000522	.399	.107906	.000614
.360	.085805	.000525	.400	.108520	.000616
.361	.086330	.000526	.401	.109136	.000619
.362	.086856	.000529	.402	.109755	.000621
.363	.087385	.000530	.403	.110376	.000624
.364	.087915	.000533	.404	.111000	.000626
.365	.088448	.000535	.405	.111626	.000629
.366	.088983	.000537	.406	.112255	.000632
.367	.089520	.000539	.407	.112887	.000634
.368	.090059	.000542	.408	.113521	.000636
.369	.090601	.000544	.409	.114157	.000639

Continued on page 130

TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.410	.114796	.000642	.450	.142617	.000755
.411	.115438	.000644	.451	.143372	.000759
.412	.116082	.000647	.452	.144131	.000762
.413	.116729	.000650	.453	.144893	.000765
.414	.117379	.000652	.454	.145658	.000768
.415	.118031	.000655	.455	.146426	.000771
.416	.118686	.000657	.456	.147197	.000774
.417	.119343	.000661	.457	.147971	.000778
.418	.120004	.000663	.458	.148749	.000781
.419	.120667	.000665	.459	.149530	.000784
.420	.121332	.000668	.460	.150314	.000787
.421	.122000	.000672	.461	.151101	.000791
.422	.122672	.000673	.462	.151892	.000793
.423	.123345	.000677	.463	.152685	.000798
.424	.124022	.000679	.464	.153483	.000800
.425	.124701	.000682	.465	.154283	.000804
.426	.125383	.000685	.466	.155087	.000807
.427	.126068	.000688	.467	.155894	.000810
.428	.126756	.000690	.468	.156704	.000814
.429	.127446	.000693	.469	.157518	.000817
.430	.128139	.000696	.470	.158335	.000821
.431	.128835	.000699	.471	.159156	.000824
.432	.129534	.000702	.472	.159980	.000827
.433	.130236	.000705	.473	.160807	.000831
.434	.130941	.000707	.474	.161638	.000834
.435	.131648	.000711	.475	.162472	.000838
.436	.132359	.000713	.476	.163310	.000841
.437	.133072	.000717	.477	.164151	.000845
.438	.133789	.000719	.478	.164996	.000848
.439	.134508	.000722	.479	.165844	.000852
.440	.135230	.000725	.480	.166696	.000855
.441	.135955	.000728	.481	.167551	.000859
.442	.136683	.000731	.482	.168410	.000863
.443	.137414	.000734	.483	.169273	.000866
.444	.138148	.000738	.484	.170139	.000869
.445	.138886	.000740	.485	.171008	.000874
.446	.139626	.000743	.486	.171882	.000877
.447	.140369	.000746	.487	.172759	.000880
.448	.141115	.000750	.488	.173639	.000885
.449	.141865	.000752	.489	.174524	.000888

Continued on page 131

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TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.490	.175412	.000891	.530	.214177	.001056
.491	.176303	.000896	.531	.215233	.001060
.492	.177199	.000900	.532	.216293	.001064
.493	.178099	.000902	.533	.217357	.001070
.494	.179001	.000907	.534	.218427	.001073
.495	.179908	.000911	.535	.219500	.001079
.496	.180819	.000914	.536	.220579	.001082
.497	.181733	.000919	.537	.221661	.001088
.498	.182652	.000922	.538	.222749	.001092
.499	.183574	.000926	.539	.223841	.001097
.500	.184500	.000930	.540	.224938	.001101
.501	.185430	.000934	.541	.226039	.001107
.502	.186364	.000938	.542	.227146	.001110
.503	.187302	.000941	.543	.228256	.001116
.504	.188243	.000946	.544	.229372	.001121
.505	.189189	.000950	.545	.230493	.001125
.506	.190139	.000954	.546	.231618	.001130
.507	.191093	.000957	.547	.232748	.001135
.508	.192050	.000962	.548	.233883	.001140
.509	.193012	.000966	.549	.235023	.001144
.510	.193978	.000970	.550	.236167	.001150
.511	.194948	.000974	.551	.237317	.001154
.512	.195922	.000978	.552	.238471	.001160
.513	.196900	.000982	.553	.239631	.001164
.514	.197882	.000987	.554	.240795	.001170
.515	.198869	.000990	.555	.241965	.001174
.516	.199859	.000995	.556	.243139	.001180
.517	.200854	.000999	.557	.244319	.001184
.518	.201853	.001003	.558	.245503	.001190
.519	.202856	.001008	.559	.246693	.001195
.520	.203864	.001012	.560	.247888	.001200
.521	.204876	.001016	.561	.249088	.001204
.522	.205892	.001020	.562	.250292	.001211
.523	.206912	.001025	.563	.251503	.001215
.524	.207937	.001029	.564	.252718	.001221
.525	.208966	.001033	.565	.253939	.001226
.526	.209999	.001038	.566	.255165	.001231
.527	.211037	.001042	.567	.256396	.001236
.528	.212079	.001047	.568	.257632	.001242
.529	.213126	.001051	.569	.258874	.001247

Continued on page 132

TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.570	.260121	.001253	.610	.314688	.001489
.571	.261374	.001258	.611	.316177	.001495
.572	.262632	.001263	.612	.317672	.001502
.573	.263895	.001269	.613	.319174	.001509
.574	.265164	.001274	.614	.320683	.001514
.575	.266438	.001280	.615	.322197	.001521
.576	.267718	.001286	.616	.323718	.001529
.577	.269004	.001291	.617	.325247	.001534
.578	.270295	.001296	.618	.326781	.001542
.579	.271591	.001302	.619	.328323	.001548
.580	.272893	.001308	.620	.329871	.001554
.581	.274201	.001313	.621	.331425	.001562
.582	.275514	.001319	.622	.332987	.001568
.583	.276833	.001325	.623	.334555	.001575
.584	.278158	.001330	.624	.336130	.001582
.585	.279488	.001336	.625	.337712	.001589
.586	.280824	.001343	.626	.339301	.001596
.587	.282167	.001347	.627	.340897	.001602
.588	.283514	.001354	.628	.342499	.001610
.589	.284868	.001359	.629	.344109	.001617
.590	.286227	.001366	.630	.345726	.001623
.591	.287593	.001371	.631	.347349	.001631
.592	.288964	.001377	.632	.348980	.001638
.593	.290341	.001383	.633	.350618	.001645
.594	.291724	.001389	.634	.352263	.001652
.595	.293113	.001396	.635	.353915	.001659
.596	.294509	.001401	.636	.355574	.001667
.597	.295910	.001407	.637	.357241	.001673
.598	.297317	.001414	.638	.358914	.001682
.599	.298731	.001419	.639	.360596	.001688
.600	.300150	.001426	.640	.362284	.001695
.601	.301576	.001431	.641	.363979	.001704
.602	.303007	.001438	.642	.365683	.001710
.603	.304445	.001445	.643	.367393	.001718
.604	.305890	.001451	.644	.369111	.001725
.605	.307341	.001456	.645	.370836	.001733
.606	.308797	.001464	.646	.372569	.001741
.607	.310261	.001469	.647	.374310	.001748
.608	.311730	.001476	.648	.376058	.001756
.609	.313206	.001482	.649	.377814	.001763

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TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.650	.379577	.001771	.690	.456762	.002106
.651	.381348	.001778	.691	.458868	.002116
.652	.383126	.001787	.692	.460984	.002124
.653	.384913	.001794	.693	.463108	.002134
.654	.386707	.001802	.694	.465242	.002143
.655	.388509	.001810	.695	.467385	.002153
.656	.390319	.001817	.696	.469538	.002161
.657	.392136	.001826	.697	.471699	.002171
.658	.393962	.001833	.698	.473870	.002180
.659	.395795	.001842	.699	.476050	.002190
.660	.397637	.001849	.700	.478240	.002199
.661	.399486	.001857	.701	.480439	.002209
.662	.401343	.001866	.702	.482648	.002218
.663	.403209	.001874	.703	.484866	.002228
.664	.405083	.001882	.704	.487094	.002238
.665	.406965	.001890	.705	.489332	.002247
.666	.408855	.001898	.706	.491579	.002257
.667	.410753	.001906	.707	.493836	.002266
.668	.412659	.001915	.708	.496102	.002277
.669	.414574	.001924	.709	.498379	.002287
.670	.416498	.001931	.710	.500666	.002296
.671	.418429	.001940	.711	.502962	.002306
.672	.420369	.001948	.712	.505268	.002316
.673	.422317	.001957	.713	.507584	.002326
.674	.424274	.001965	.714	.509910	.002336
.675	.426239	.001974	.715	.512246	.002346
.676	.428213	.001982	.716	.514592	.002356
.677	.430195	.001991	.717	.516948	.002367
.678	.432186	.00200	.718	.519315	.002377
.679	.434186	.002008	.719	.521692	.002387
.680	.436194	.002017	.720	.524079	.002397
.681	.438211	.002026	.721	.526476	.002407
.682	.440237	.002034	.722	.528883	.002418
.683	.442271	.002044	.723	.531301	.002429
.684	.444315	.002052	.724	.533730	.002439
.685	.446367	.002061	.725	.536169	.002449
.686	.448428	.002070	.726	.538618	.002459
.687	.450498	.002079	.727	.541077	.002471
.688	.452577	.002088	.728	.543548	.002481
.689	.454665	.002097	.729	.546029	.002491

Continued on page 134

TABLE XXVI — *Continued*
S VALUES
FOR PIPE CONNECTIONS

$$S = \frac{Ed^2}{D^2}$$

d/D	S	DIFF.	d/D	S	DIFF.
.730	.548520	.002503	.740	.574034	.002611
.731	.551023	.002513	.741	.576645	.002624
.732	.553536	.002524	.742	.579269	.002634
.733	.556060	.002535	.743	.581903	.002646
.734	.558595	.002545	.744	.584549	.002657
.735	.561140	.002557	.745	.587206	.002668
.736	.563697	.002568	.746	.589874	.002680
.737	.566265	.002578	.747	.592554	.002691
.738	.568843	.002590	.748	.595245	.002703
.739	.571433	.002601	.749	.597948	.002714
			.750	.600662	

SECTION II

CHART COMPUTATIONS

Before taking up the details of the process involved in computing charts, let us briefly consider a point which, when thoroughly understood, will reduce to a minimum the time of figuring charts.

It is common practice in chart computing work, to carry the results of each step to five, six, or seven place of figures. For example: 1,567,925 cu. ft. The operator believes that because those seven figures, or digits, as they are known mathematically, are the correct result of the final operation in computing, they must represent the actual amount of gas passed by the meter in question. This, however, is not true, for the result could be set down as 1,568,000 cu. ft. and be just as accurate an indication of the quantity of gas as the former number. This latter number contains only four significant figures, and the following paragraphs, under Precision of Measurement, will explain why it is a waste of time, and why the results are no more accurate if a greater number of significant figures are used, than the attainable accuracy of the result warrants.

Precision of Measurement

A significant figure is any digit (including zero) used to denote the amount of the quantity in the place in which it stands; but when zero is used to locate the decimal point it is not significant. Thus in the number 0.02060 the first two zeros are not significant figures. That between the 2 and the 6 denotes a quantity and is therefore significant. The zero following the 6 indicates that the measurement is sufficiently accurate to indicate that the quantity in the place in which it stands is nearer to zero than to any other number, and is there-

fore significant. In the number 385,000 the last three zeros may or may not be significant, depending upon whether or not the quantities represented by these places of figures were measured. If they are retained merely to indicate the position of the decimal point, as is usually the case (except in abstract numbers), they are not significant.

From a study of the principles of significant figures (Computation Rules, by Silas W. Holman) it will be observed that an accuracy of one per cent or better in the final result of any computation involving the multiplication of less than twenty factors, may be assured by the use of four significant figures. It will also be seen that in any multiplication or division, the percentage accuracy of the product or quotient cannot exceed that of the factor whose percentage accuracy is least; or in other words, if several numbers are multiplied or divided, a given percentage error in any one of them will produce the same percentage error in the result.

Furthermore, where a number is raised to any power n, the percentage error in the result is equal to n times its value in the data. The use of more than four places is worse than useless. It adds nothing to the accuracy of the result, although increasing materially the labor of computing, and the liability of mistakes. The use of five places instead of four nearly doubles the labor, and using six places instead of four nearly trebles it.

Directions for Computing Results

The simplified formula for gas flow is

$$Q = C\sqrt{hP} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad \textit{Equation 66}$$

in which

Q = quantity of gas (cubic feet) flowing for any given period.
C = coefficient for the same period.

h = average differential pressure for that period.

P = average absolute static pressure for that period.

A complete description of the coefficient C, together with a set of tables giving the hourly coefficient corresponding to various orifice sizes will be found on pages 88 and 94–97 incl.

The square root of the values of h and P, as indicated in the foregoing equation, must be determined as a part of the computation, but in order to facilitate this step, reference can be made to a set of multiplier tables at the end of this section. These tables contain the values of the square root of h and P.

One more step which saves labor in computing is the use of Extension Tables.

A part of a page from a commonly used extension book is shown in Fig. 1674, page 138. The cut has been arranged with the center sections of the page removed, in order to bring the figures more nearly to full size. The figures shown are approximately two-thirds size, and the actual size of a page is 9×16.

The extension is the product of the square root of h and P, or the product of the multipliers of h and P, found in the multiplier tables at the end of this section.

The commonly used extension books are so arranged that each page contains the extensions for either one or five static pressures. In the foregoing illustration the page is one static pressure, namely 144 lbs. The differential pressures are the figures in the vertical columns under H and in the horizontal columns at the top and bottom of the page. With this arrangement, extensions may be found for differential pressures each tenth of an inch.

The use of these Extension Tables eliminates the necessity of multiplying together the values for h and P, found in the

H.	.0	.1	.2	.7	.8	.9	H.
0.		3.980	5.629	10.530	11.257	11.940	0.
1.	12.586	13.200	13.787	16.410	16.885	17.348	1.
2.	17.799	18.238	18.668	20.680	21.060	21.433	2.
3.	21.799	22.159	22.514	24.209	24.534	24.855	3.
4.	25.171	25.484	25.793	27.285	27.574	27.860	4.
5.	28.142	28.423	28.700	30.048	30.310	30.571	5.
6.	30.829	31.084	31.338	32.577	32.820	33.060	6.
7.	33.299	33.536	33.771	34.924	35.150	35.375	7.
8.	35.598	35.820	36.040	37.122	37.335	37.547	8.
9.	37.757	37.966	38.174	39.198	39.400	39.600	9.
10.	39.799	39.998	40.196	41.169	41.361	41.552	10.
11.	41.742	41.931	42.120	43.050	43.233	43.416	11.
12.	43.598	43.779	43.960	44.852	45.028	45.204	12.
13.	45.378	45.553	45.726	46.584	46.754	46.923	13.
14.	47.091	47.259	47.427	48.254	48.418	48.581	14.
15.	48.744	48.906	49.068	49.869	50.027	50.185	15
16.	50.343	50.500	50.656	51.432	51.586	51.739	16.
17.	51.892	52.045	52.197	52.950	53.099	53.248	17.
18.	53.397	53.545	53.692	54.425	54.570	54.715	18.
19.	54.860	55.004	55.148	55.861	56.003	56.144	19.
20.	56.285	56.419	56.566	57.262	57.400	57.537	20.
21.	57.675	57.812	57.949	58.628	58.763	58.898	21.
22.	59.032	59.166	59.300	59.964	60.096	60.228	22.
53.	91.625	91.712	91.798	92.223	92.314	92.400	53.
54.	92.486	92.571	92.657	93.083	93.168	93.253	54.
55.	93.338	93.423	93.508	93.930	94.014	94.099	55.
56.	94.183	94.267	94.351	94.770	94.853	94.937	56.
57.	95.020	95.103	95.186	95.602	95.685	95.767	57.
58.	95.850	95.932	96.015	96.427	96.509	96.591	58.
59.	96.673	96.755	96.836	97.244	97.326	97.407	59.
60.	97.488	97.570	97.651	98.056	98.136	98.217	60.
61.	98.298	98.378	98.459	98.860	98.940	99.020	61.
62.	99.100	99.180	99.260	99.658	99.737	99.817	62.
63.	99.896	99.975	100.053	100.450	100.530	100.610	63.
64.	100.685	100.764	100.841	101.234	101.311	101.390	64.
65.	101.470	101.550	101.630	102.015	102.091	102.170	65.
66.	102.245	102.325	102.400	102.789	102.865	102.941	66.
67.	103.019	103.095	103.171	103.555	103.631	103.709	67.
68.	103.785	103.861	103.935	104.318	104.394	104.469	68.
69.	104.545	104.620	104.699	105.075	105.149	105.225	69.
70.	105.300	105.375	105.449	105.825	105.899	105.975	70.
71.	106.049	106.125	106.199	106.570	106.641	106.719	71.
72.	106.791	106.869	106.940	107.310	107.385	107.459	72.
73.	107.531	107.605	107.679	108.050	108.120	108.194	73.
74.	108.268	108.339	108.411	108.780	108.850	108.921	74.
75.	108.995	109.069	109.140	109.501	109.575	109.649	75.
H.	.0	.1	.2	7	.8	.9	H.

Fig. 1674

multiplier tables, and by further confining the extension values to four significant figures the amount of labor involved is minimized.

The process of determining the flow of gas is therefore simplified to multiplying the hourly coefficient by the total extension.

There are four methods of computing flow-meter charts.

(*a*) The "Period" or inspection method, in which the differential and static pressures are observed for each fifteen-minute or hourly period.

(*b*) The McGaughy Integrator method.

(*c*) Observation method.

(*d*) The Square Root Planimeter method (see Section III).

(a) Period Method

CASE I. When gas is passing for full twenty-four hours and charts are readable for the entire period.

This may be handled in either one of two ways. The readings for each fifteen-minute or hourly period may be set down directly on the chart, together with their corresponding extensions, as shown in Fig. 1672, page 140, or entered on a tabular form. In either case extreme care must be used to see that the differential and static readings are taken for corresponding periods.

The total of the extensions in Fig. 1672 is 1628.61. Reduced to four significant figures this amount becomes 1629. If this be multiplied by an assumed hourly coefficient of 300, the result is 488,700, which is the daily flow of gas in cubic feet. *

CASE II. When gas is passing for twenty-four hours, but for any reason the charts are not readable for the entire period.

If the flow of gas is uniform throughout the day and night it is customary to assume the average hourly flow for the readable period as average for the twenty-four hours. Read the

* See footnote on page 140.

differential and static for as many *corresponding* readable hourly periods as possible. Add their extensions. Multiply this sum by 24 and divide by the number of hourly periods for which readable values were obtained. Multiply this result by the

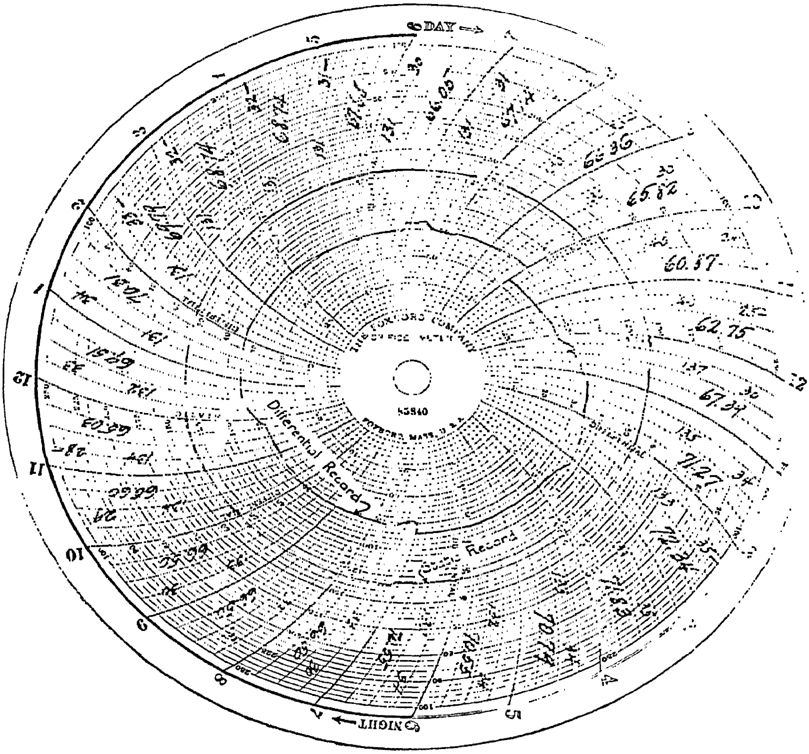


Fig. 1672

hourly coefficient of the plate used, and the product will be the number of cubic feet of gas passed in twenty-four hours.

If the flow of gas varies widely throughout the day, it is customary to compute the readable portion of the chart and add

* Note: Nine errors have been made in reading the above chart. The accurate chart computer should be able to pick out these errors.

the average value corresponding to the illegible period. This value is obtained from charts preceding and following the one in question.

CASE III. When gas is passing for only a portion of twenty-four hours.

When readable values of both h and P may be obtained for each hourly period during which gas is flowing, the procedure is exactly as in Case I. The sum of the extensions for the number of periods involved, multiplied by the hourly coefficient, will give the flow of gas for that time.

When readable values cannot be obtained for each period of actual flow, proceed as in Case II, except that the sum of the extensions of the *corresponding* readable values should be multiplied by the number of hours during which gas was actually passing, and divided by the number of hourly periods for which readable values were obtained. This result, multiplied by the hourly coefficient, will give the quantity of gas passed during the actual time of flow.

(b) The McGaughy Integrator Method

The latest development in chart computing devices is the McGaughy Integrator. It integrates an infinite number of instantaneous square roots of products of simultaneous pressure and differential values. It is particularly adapted for use with Foxboro Meters because in integrating simultaneous values of differential and static it is necessary that the two records be perfectly synchronized. The Foxboro Meter is the one meter which produces synchronized records.

In using this integrator the chart is revolved by a motor while the operator guides two pens over the chart records. The machine is provided with two control handles to move the pens across the face of the chart and with a foot control to regulate the speed of the chart. The reading is taken from a

counter. The difference between the counter reading at the start and the end of a record is the Extension.

The ink lines which this machine superimposes on the original chart records make it possible to check the operation at a glance.

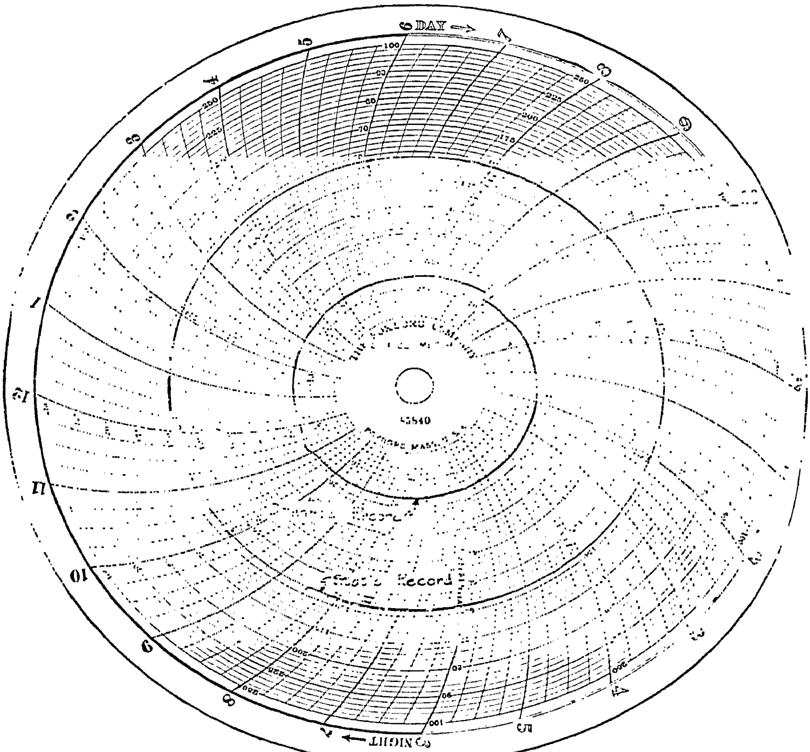


Fig. 1670

(c) Observation Method

Occasionally the records run so uniform that the average for the entire period may be determined at a glance without introducing a serious error. Such records are shown in Fig. 1670,

page 142. The average static pressure is 144 lbs.; the average differential, 15.5″. The extension for these values is 49.55. Assuming the hourly coefficient to be 415.6, then 415.6 × 49.55 = 20,590 cu. ft. of gas per hour which multiplied by 24 gives 494,200 cu. ft. of gas per day.

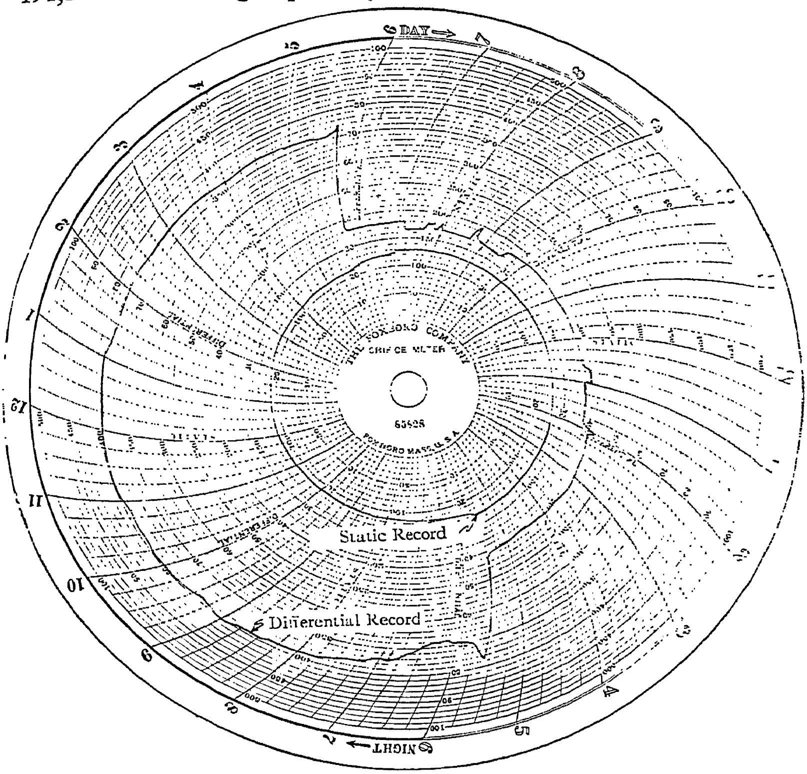


Fig. 1671

Inaccuracy of the Radial Planimeter

Referring to Fig. 1671, the average for the high period is approximately 72, and for the low period approximately 38.

If the entire record were averaged at one operation by a Planimeter, the result would be 55, and the square root of 55 is 7.416. If, however, the periods were averaged separately and the average square root determined, the results would be the square root of 72 (8.485) plus the square root of 38 (6.164), or 14.649 divided by 2, which would give 7.325. The error in this particular case is not very large, but it would increase rapidly as the difference between the high and low periods increased. For example, if the foregoing high period averaged approximately 90, and the low period 20, the average for the entire record would still be 55 and its square root 7.416, but the square root of 90 (9.847) plus the square root of 20 (4.472), or 13.959, divided by 2, would be 6.979. Therefore it is obvious that the desired result should be the average square root and not the square root of the average.

Time Lag in Pressure Records

The importance of synchronism of static and differential pressure records has never been sufficiently stressed. The closeness with which both pens follow the same arc is fully as important as calibration of the instrument. There is a very common belief that the effect of a time lag in the pressure record will average out in the period of a day. The fallacy of this assumption may be readily seen by consideration of an exaggerated case.

Take the example of a measuring station in which the differential pen lags one hour behind the static pen on the chart time scale. The operating pressure of the station is 34.6 lbs. but the station is fed by a long line on which the pressure drop is 51 lbs. When the station shuts down, the pressure builds up to 85.6 lbs. Suppose this occurs at intervals of one hour, the differential pressure changing from 25″ to 0″. The chart computer, failing to take into account the time lag, accepts the 25″

and 85.6 lbs. readings as simultaneous and likewise the 0″ 34.6 lbs. readings as shown on the chart. The total of the extension is then

$$(12 \times 5 \times 10) \text{ plus } (12 \times 0 \times 7) \text{ equals } 600,$$

whereas, had the chart been correctly computed, the total extension would have been

$$(12 \times 5 \times 7) \text{ plus } (12 \times 0 \times 10) \text{ equals } 420$$

The computation error in this case would be slightly over 42%.

A very common case in which the time lag is an important factor will be found in the measurement of casinghead gas. During the night while the delivery from the well is low, the static pressure drops (vacuum increases); that is, the pressure at the Meter approaches that at the vacuum station. But in the morning the well in being pumped increases its delivery and the static pressure increases (vacuum decreases). It may readily be seen that this produces a relation between static and differential pressures which is the reverse of the instance first described. The resulting error will be in the opposite direction.

Thus it may be seen that always there is a relation between flow and static pressure, and that in all cases where there is such a relation, an appreciable lag between fluctuating records will result in an error in measurement.

SECTION III

THE TYPE NO. 3 PLANIMETER

(Square Root)

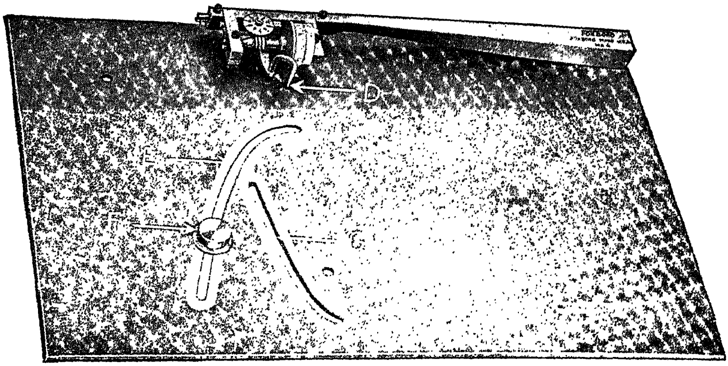


Fig. 3119
FOXBORO SQUARE ROOT PLANIMETER

THE Foxboro Square Root Planimeter shown above is designed for the integration of any 12″ Foxboro Flow Meter Chart. It mechanically averages the square roots of the differential and static readings recorded on the chart. That is, instead of averaging h and P in the formula $Q = C\sqrt{hP}$, this Planimeter averages $\sqrt{h}$ and $\sqrt{P}$. It therefore eliminates all errors caused by the difference between the square root of the average and the average square root.

The No. 3 Type Planimeter is made in the following models:

The 3A Planimeter has a single curved slot identical with slot E, Fig. 3119, above, and can be used on any chart from Type "T" or Type "C" Flow Meter except those with reverse scale.

The 3B Planimeter has an extra curved slot G, Fig. 3119, designed especially for chart from casinghead gas meter (Type "C") with static range 30″—0—25 lbs. reverse scale, but may be used with other reverse scale charts by using proper factor.

The 3C Planimeter has a single curved slot corresponding to slot E, Fig. 3119, and can be used on any chart from a 100 or 200 Type Instrument except those with reverse scale.

The 3D Planimeter has an extra curved slot corresponding to slot G, Fig. 3119, designed especially for charts from 200 Type Instruments, with static range 30″—0—25 lbs. reverse scale, but may be used with other reverse scale charts by using proper factor.

The following instructions also apply to any No. 3 Type Planimeter made for the planimetering of charts from other types of Flow Meters.

Operating and Reading Planimeter

Planimetering is performed in the following manner: Place the center of the chart on Planimeter hub F (Fig. 3119) and bring the chart to a position such that the record to be planimetered rests under the gooseneck pointer D. Note the registration of the Planimeter; rotate the chart clockwise and again note the registration. Subtract the initial from the final registration and call the resulting Planimeter reading R.

Initial and final registrations of the Planimeter should always be noted at points equidistant from the center of the chart. For example, if the integration is started at 50″ differential and completed at 63″ differential on the 8 a.m. time arc, the chart must be moved so that the pointer follows the 8 a.m. time arc back to 50″ differential and final registration noted at that point. Otherwise, a slight error may be introduced.

Instructions for Operating Square Root Planimeters on Gas Flow Meter Charts

Method 1.

Planimeter the differential record in the manner described under operating and reading planimeter. The reading obtained multiplied by one of the factors given below corresponding to the differential range of the instrument will give the average square root of the differential for the 24-hour period.

Table XXVII

Differential Range	*Factor*
0 to 20	.8944
0 to 50	1.4142
0 to 60	1.5492
0 to 100	2.0000

On many charts, the static pressure is so constant that it may be averaged by observation. On other charts, the square root planimeter may be used with a table showing the static readings corresponding to planimeter readings.

Knowing the value of static pressure, the value of the square root of static pressure may be obtained from a table of multipliers, such as that on pages 134, 135 and 136. This value multiplied by the average square root of the differential (obtained as described in the first paragraph of this section) times the 24-hour coefficient will give the total flow for the period.

METHOD 2.

Some users of the square root planimeters prefer to operate it purely as a reference, obtaining the corresponding chart readings for differential and static pressures from tables. A zero reading on the planimeter corresponds to a zero reading on the chart, and the reading of 5 on the planimeter corresponds to the outside scale reading of the chart. Similarly, each intermediate planimeter reading corresponds to some intermediate

reading on the chart. Complete instructions and tables covering method 2 are given in Planimeter Instruction Form No. 654A.

Planimetering Charts Having Wide Changes in Static Pressure

The differential reading may vary an infinite amount without decreasing the accuracy of the square root planimeter determinations. However, if there is over a 10% change in the value of absolute *static pressure* for any appreciable period of time, the charts should be divided into periods such that the change in static pressure within the period is less than 10%. In doing this, the planimeter readings for the static pressure (but not those for the differential) should be reduced to a 24-hour equivalent. The sum of the readings of these periods gives the total for the day.

Multiplier Tables

Extension tables, in order to cover the numerous combinations of differential and static pressures, are bulky and may not always be available. The same number of combinations may be covered in two brief tables of separate multipliers which if multiplied together give the extension for the corresponding differential and static pressure. For convenience of the customer, these multipliers are supplied in the following tables.

Table XIII

Differential Pressure Multipliers

1–20 inches of water in tenths inches
20–100 inches of water in inches

h	Mult.	h	Mult.	h	Mult.	h	Mult.	h	Mult.
1.0	1.000	6.5	2.550	12.0	3.464	17.5	4.183	50	7.071
.1	1.049	.6	2.569	.1	3.478	.6	4.195	51	7.141
.2	1.095	.7	2.588	.2	3.492	.7	4.207	52	7.211
.3	1.140	.8	2.608	.3	3.506	.8	4.219	53	7.280
.4	1.183	.9	2.627	.4	3.521	.9	4.231	54	7.348
1.5	1.225	7.0	2.646	12.5	3.535	18.0	4.243	55	7.416
.6	1.265	.1	2.665	.6	3.549	.1	4.255	56	7.483
.7	1.304	.2	2.683	.7	3.563	.2	4.266	57	7.550
.8	1.342	.3	2.702	.8	3.577	.3	4.278	58	7.616
.9	1.378	.4	2.720	.9	3.592	.4	4.289	59	7.681
2.0	1.414	7.5	2.739	13.0	3.606	18.5	4.301	60	7.746
.1	1.449	.6	2.757	.1	3.620	.6	4.313	61	7.810
.2	1.483	.7	2.775	.2	3.633	.7	4.324	62	7.874
.3	1.517	.8	2.793	.3	3.647	.8	4.336	63	7.937
.4	1.549	.9	2.811	.4	3.660	.9	4.347	64	8.000
2.5	1.581	8.0	2.828	13.5	3.674	19.0	4.359	65	8.062
.6	1.612	.1	2.846	.6	3.687	.1	4.370	66	8.124
.7	1.643	.2	2.864	.7	3.701	.2	4.382	67	8.185
.8	1.673	.3	2.881	.8	3.715	.3	4.393	68	8.246
.9	1.703	.4	2.898	.9	3.728	.4	4.404	69	8.307
3.0	1.732	8.5	2.915	14.0	3.742	19.5	4.416	70	8.367
.1	1.761	.6	2.933	.1	3.755	.6	4.427	71	8.426
.2	1.789	.7	2.950	.2	3.768	.7	4.438	72	8.485
.3	1.817	.8	2.966	.3	3.781	.8	4.449	73	8.544
.4	1.844	.9	2.983	.4	3.794	.9	4.461	74	8.602
3.5	1.871	9.0	3.000	14.5	3.808	20.0	4.472	75	8.660
.6	1.897	.1	3.017	.6	3.821	21	4.583	76	8.718
.7	1.924	.2	3.033	.7	3.834	22	4.690	77	8.775
.8	1.949	.3	3.050	.8	3.847	23	4.796	78	8.832
.9	1.975	.4	3.066	.9	3.860	24	4.899	79	8.888
4.0	2.000	9.5	3.082	15.0	3.873	25	5.000	80	8.944
.1	2.025	.6	3.098	.1	3.886	26	5.099	81	9.000
.2	2.049	.7	3.114	.2	3.898	27	5.196	82	9.055
.3	2.074	.8	3.130	.3	3.911	28	5.292	83	9.110
.4	2.098	.9	3.146	.4	3.924	29	5.385	84	9.165
4.5	2.121	10.0	3.162	15.5	3.936	30	5.477	85	9.220
.6	2.145	.1	3.178	.6	3.949	31	5.568	86	9.274
.7	2.168	.2	3.193	.7	3.962	32	5.657	87	9.327
.8	2.191	.3	3.209	.8	3.975	33	5.745	88	9.381
.9	2.214	.4	3.224	.9	3.987	34	5.831	89	9.434
5.0	2.236	10.5	3.240	16.0	4.000	35	5.916	90	9.487
.1	2.258	.6	3.256	.1	4.012	36	6.000	91	9.539
.2	2.280	.7	3.271	.2	4.025	37	6.083	92	9.592
.3	2.302	.8	3.287	.3	4.037	38	6.164	93	9.644
.4	2.324	.9	3.302	.4	4.049	39	6.245	94	9.695
5.5	2.345	11.0	3.317	16.5	4.062	40	6.325	95	9.747
.6	2 366	1	3 331	6	4 074	41	6.403	96	9.798
.7	2.387	.2	3.346	.7	4.086	42	6.481	97	9.849
.8	2.408	.3	3.361	.8	4.098	43	6.557	98	9.899
.9	2.429	.4	3.375	.9	4.111	44	6.633	99	9.950
6.0	2.449	11.5	3.390	17.0	4.123	45	6.708	100	10.000
.1	2.470	.6	3.405	.1	4.135	46	6.782	...	....
.2	2.490	.7	3.419	.2	4.147	47	6.856	...	....
.3	2.510	.8	3.434	.3	4.159	48	6.928	. .	....
.4	2.530	.9	3.449	.4	4.171	49	7.000	.	....

Table XXVIII
Static Pressure Multipliers
(Below Atmospheric Pressure 14.4 lbs. per sq. in.)
0–29 inches mercury vacuum in tenths inches

P	Mult.	P	Mult.	P	Mult.	P	Mult.	P	Mult.
0.0	3.795	6.0	3.384	12.0	2.917	18.0	2.358	24.0	1.616
.1	3.788	.1	3.377	.1	2.908	.1	2.347	.1	1.600
.2	3.782	.2	3.369	.2	2.899	.2	2.337	.2	1.584
.3	3.775	.3	3.362	.3	2.891	.3	2.326	.3	1.568
.4	3.769	.4	3.355	.4	2.883	.4	2.315	.4	1.552
0.5	3.762	6.5	3.348	12.5	2.874	18.5	2.305	24.5	1.536
.6	3.755	.6	3.340	.6	2.865	.6	2.294	.6	1.520
.7	3.749	.7	3.333	.7	2.857	.7	2.283	.7	1.504
.8	3.742	.8	3.326	.8	2.848	.8	2.272	.8	1.488
.9	3.736	.9	3.318	.9	2.840	.9	2.262	.9	1.472
1.0	3.729	7.0	3.311	13.0	2.831	19.0	2.251	25.0	1.456
.1	3.722	.1	3.304	.1	2.822	.1	2.240	.1	1.438
.2	3.716	.2	3.296	.2	2.813	.2	2.229	.2	1.420
.3	3.709	.3	3.289	.3	2.805	.3	2.217	.3	1.402
.4	3.703	.4	3.281	.4	2.796	.4	2.206	.4	1.384
1.5	3.696	7.5	3.274	13.5	2.787	19.5	2.195	25.5	1.367
.6	3.689	.6	3.266	.6	2.778	.6	2.184	.6	1.349
.7	3.683	.7	3.259	.7	2.769	.7	2.173	.7	1.331
.8	3.676	.8	2.251	.8	2.761	.8	2.161	.8	1.313
.9	3.670	.9	3.244	.9	2.752	.9	2.150	.9	1.295
2.0	3.663	8.0	3.236	14.0	2.743	20.0	2.139	26.0	1.277
.1	3.657	.1	3.228	.1	2.734	.1	2.127	.1	1.256
.2	3.650	.2	3.221	.2	2.725	.2	2.115	.2	1.235
.3	3.643	.3	3.213	.3	2.716	.3	2.104	.3	1.214
.4	3.636	.4	3.205	.4	2.707	.4	2.092	.4	1.193
2.5	3.629	8.5	3.196	14.5	2.698	20.5	2.080	26.5	1.172
.6	3.623	.6	3.190	.6	2.688	.6	2.068	.6	1.151
.7	3.616	.7	3.182	.7	2.679	.7	2.056	.7	1.130
.8	3.609	.8	3.174	.8	2.670	.8	2.045	.8	1.109
.9	3.602	.9	3.167	.9	2.661	.9	2.033	.9	1.088
3.0	3.595	9.0	3.159	15.0	2.652	21.0	2.021	27.0	1.067
.1	3.588	.1	3.151	.1	2.643	.1	2.009	.1	1.041
.2	3.581	.2	3.143	.2	2.633	.2	1.996	.2	1.015
.3	3.574	.3	3.135	.3	2.624	.3	1.984	.3	.989
.4	3.567	.4	3.127	.4	2.614	.4	1.971	.4	.960
3.5	3.561	9.5	3.120	15.5	2.605	21.5	1.959	27.5	.937
.6	3.554	.6	3.112	.6	2.596	.6	1.946	.6	.910
.7	3.547	.7	3.104	.7	2.586	.7	1.934	.7	.884
.8	3.540	.8	3.096	.8	2.577	.8	1.921	.8	.858
.9	3.533	.9	3.088	.9	2.567	.9	1.909	.9	.832
4.0	3.526	10.0	3.080	16.0	2.558	22.0	1.896	28.0	.806
.1	3.519	.1	3.072	.1	2.548	.1	1.883	.1	.765
.2	3.512	.2	3.064	.2	2.538	.2	1.869	.2	.724
.3	3.505	.3	3.056	.3	2.529	.3	1.856	.3	.684
.4	3.498	.4	3.048	.4	2.519	.4	1.842	.4	.644
4.5	3.491	10.5	3.040	16.5	2.509	22.5	1.829	28.5	.603
.6	3.484	.6	3.032	.6	2.499	.6	1.815	.6	.562
.7	3.477	.7	3.024	.7	2.489	.7	1.802	.7	.522
.8	3.470	.8	3.016	.8	2.480	.8	1.788	.8	.481
.9	3.463	.9	3 008	.9	2.470	.9	1.775	.9	.441
5.0	3.456	11.0	3.000	17.0	2.460	23.0	1.761	29.0	.400
.1	3.449	.1	2.992	.1	2.450	.1	1.747	...	...
.2	3.442	.2	2.983	.2	2.440	.2	1.732	...	...
.3	3.434	.3	2.975	.3	2.429	.3	1.718	...	...
.4	3.427	.4	2.967	.4	2.419	.4	1.703	...	...
5.5	3.420	11.5	2.959	17.5	2.409	23.5	1.689	...	...
.6	3.413	.6	2.950	.6	2.399	.6	1.674	...	...
.7	3.406	.7	2.942	.7	2.389	.7	1.660	...	...
.8	3.398	.8	2.934	.8	2.378	.8	1.645	...	...
.9	3.391	.9	2.925	.9	2.368	.9	1.631	...	...

Continued on page 152

Table XXVIII — *Continued*

Static Pressure Multipliers

(Above Atmospheric Pressure 14.4 lbs. per sq. in.)

P	Mult.	P	Mult.	P	Mult.	P	Mult.
0	3.795						
1	3.924	51	8.087	101	10.74	151	12.86
2	4.050	52	8.149	102	10.79	152	12.90
3	4.171	53	8.210	103	10.84	153	12.94
4	4.290	54	8.270	104	10.88	154	12.98
5	4.405	55	8.331	105	10.93	155	13.02
6	4.517	56	8.390	106	10.97	156	13.06
7	4.626	57	8.450	107	11.02	157	13.09
8	4.733	58	8.509	108	11.07	158	13.13
9	4.837	59	8.567	109	11.11	159	13.17
10	4.940	60	8.626	110	11.16	160	13.21
11	5.040	61	8.683	111	11.20	161	13.25
12	5.138	62	8.741	112	11.24	162	13.28
13	5.235	63	8.798	113	11.29	163	13.32
14	5.329	64	8.854	114	11.33	164	13.36
15	5.422	65	8.911	115	11.38	165	13.40
16	5.514	66	8.967	116	11.42	166	13.43
17	5.604	67	9.022	117	11.47	167	13.47
18	5.692	68	9.077	118	11.51	168	13.51
19	5.779	69	9.132	119	11.55	169	13.54
20	5.865	70	9.187	120	11.60	170	13.58
21	5.950	71	9.241	121	11.64	171	13.62
22	6.033	72	9.295	122	11.68	172	13.65
23	6.116	73	9.349	123	11.72	173	13.69
24	6.197	74	9.402	124	11.77	174	13.73
25	6.277	75	9.455	125	11.81	175	13.76
26	6.356	76	9.508	126	11.85	176	13.80
27	6.434	77	9.560	127	11.89	177	13.84
28	6.512	78	9.612	128	11.94	178	13.87
29	6.588	79	9.664	129	11.98	179	13.91
30	6.663	80	9.716	130	12.02	180	13.94
31	6.738	81	9.767	131	12.06	181	13.98
32	6.812	82	9.818	132	12.10	182	14.02
33	6.885	83	9.869	133	12.14	183	14.05
34	6.957	84	9.920	134	12.19	184	14.09
35	7.029	85	9.970	135	12.23	185	14.12
36	7.099	86	10.02	136	12.27	186	14.16
37	7.169	87	10.07	137	12.31	187	14.19
38	7.239	88	10.12	138	12.35	188	14.23
39	7.308	89	10.17	139	12.39	189	14.26
40	7.376	90	10.22	140	12.43	190	14.30
41	7.443	91	10.27	141	12.47	191	14.33
42	7.510	92	10.32	142	12.51	192	14.37
43	7.576	93	10.36	143	12.55	193	14.40
44	7.642	94	10.41	144	12.59	194	14.44
45	7.707	95	10.46	145	12.63	195	14.47
46	7.772	96	10.51	146	12.67	196	14.51
47	7.836	97	10.56	147	12.71	197	14.54
48	7.899	98	10.60	148	12.75	198	14.57
49	7.962	99	10.65	149	12.79	199	14.61
50	8.025	100	10.70	150	12.83	200	14.64

Continued on page 153

Table XXVIII — *Continued*
Static Pressure Multipliers
(Above Atmospheric Pressure 14.4 lbs. per sq. in.)

P	Mult.	P	Mult.	P	Mult.	P	Mult.
201	14.68	241	15.98	281	17.19	321	18.31
202	14.71	242	16.01	282	17.21	322	18.34
203	14.74	243	16.04	283	17.24	323	18.37
204	14.78	244	16.07	284	17.27	324	18.39
205	14.81	245	16.10	285	17.30	325	18.42
206	14.85	246	16.14	286	17.33	326	18.45
207	14.88	247	16.17	287	17.36	327	18.48
208	14.91	248	16.20	288	17.39	328	18.50
209	14.95	249	16.23	289	17.42	329	18.53
210	14.98	250	16.26	290	17.45	330	18.56
211	15.01	251	16.29	291	17.47	331	18.58
212	15.05	252	16.32	292	17.50	332	18.61
213	15.08	253	16.35	293	17.53	333	18.64
214	15.11	254	16.38	294	17.56	334	18.66
215	15.15	255	16.41	295	17.59	335	18.69
216	15.18	256	16.44	296	17.62	336	18.72
217	15.21	257	16.47	297	17.65	337	18.74
218	15.24	258	16.50	298	17.67	338	18.77
219	15.28	259	16.53	299	17.70	339	18.80
220	15.31	260	16.56	300	17.73	340	18.82
221	15.34	261	16.59	301	17.76	341	18.85
222	15.37	262	16.62	302	17.79	342	18.88
223	15.41	263	16.65	303	17.81	343	18.90
224	15.44	264	16.68	304	17.84	344	18.93
225	15.47	265	16.71	305	17.87	345	18.96
226	15.50	266	16.74	306	17.90	346	18.98
227	15.54	267	16.77	307	17.93	347	19.01
228	15.57	268	16.80	308	17.95	348	19.04
229	15.60	269	16.83	309	17.98	349	19.06
230	15.63	270	16.86	310	18.01	350	19.09
231	15.66	271	16.89	311	18.04	...	....
232	15.70	272	16.92	312	18.07	...	....
233	15.73	273	16.95	313	18.09	...	....
234	15.76	274	16.98	314	18.12	...	....
235	15.79	275	17.01	315	18.15	...	....
236	15.82	276	17.04	316	18.18	...	....
237	15.85	277	17.07	317	18.20	...	....
238	15.89	278	17.10	318	18.23	...	....
239	15.92	279	17.13	319	18.26	...	....
240	15.95	280	17.16	320	18.29	...	....

SECTION IV

FUNDAMENTALS OF COMMERCIAL MEASUREMENT

This section will be devoted to the treatment of the theory of the orifice type flow meter from a practical point of view. Its purpose is to give a conception of the elements involved in orifice measurement which will explain the phenomena likely to be encountered in commercial measurement.

The inaccuracies discussed are only met when the orifice type flow meter is used improperly; they have been covered in a belief that satisfaction in the use of any precision apparatus is dependent on a realization of its limitations. As inaccuracies, due to use beyond the range of conditions for which orifices were calibrated, may be either prevented by proper precautions or allowed for in the calculated results, a proper knowledge of their magnitude may enable the user to adapt his meter to adverse conditions, still maintaining the high degree of accuracy for which this type of flow meter is recognized.

Because the difficulties of obtaining check measurements increase rapidly as the limits of allowable error are decreased, it is found necessary to establish commercial limits for gas measurement consistent with the wide variety of field conditions under which they must be made. A hundred pounds of coal measured on a set of platform scales seems a very tangible quantity as long as the limits of accuracy are plus or minus one pound; but, when the limits are made plus or minus one grain, it is found that the weight varies from day to day with change in the moisture content. There are limits upon the exactness with which it is possible to measure a thing of the apparent perma-

nence of a steel bar. In fact there is no such thing as exact measurement. Commercial limits are those obtainable by practical methods usable under operating conditions. Laboratory limits, in contrast, are obtainable only by endless refinements of method and elimination of variables.

The measurement of gas by any means is inherently difficult due to the large number of variables involved. Temperature, pressure, and humidity all affect the number of molecules of any specific gas contained in a cubic foot. If a certain quantity of gas is sealed in a large capacity holder, it will be found that the volume occupied will change widely from hour to hour. This effect is so pronounced that it is found difficult to obtain holder measurements within less than one per cent, even though corrections are made for temperature, pressure and humidity.

After a thorough study of the other means available, it is not difficult to understand why the orifice type flow meter, in spite of its number of minor variables, has stood the test of time as a standard of accuracy in the measurement of compressible fluids.

The hydraulic formula, which is used in commercial measurement because of its simplicity, is a derivation from the law of conservation of energy. The values used in its determination are based upon physical relations and units of measurement. If all the assumptions made in its derivation were fulfilled, coefficients could be computed without experimental data; likewise, if all the deviations from its assumptions were separated and correction factors for each applied, the hydraulic equation might be used with accurate results under any operating conditions. A great deal has been done toward isolating these effects, but the number of separate factors involved make it safer to determine the total resultant experimentally than to attempt to isolate the individual components. This resultant factor, termed "E" in the flow equation, is the experimentally

determined ratio of actual to hypothetical flow. Its value remains fairly constant for a single ratio of $\frac{d}{D}$, regardless of a reasonable range of operating conditions.

A.G.A. Gas Measurement Committee Report No. 2 breaks down the value of E into two additional factors: F_r and Y. This procedure, while adding somewhat to the complexity of calculation of rate of flow, nevertheless narrows the measurement tolerance and at the same time increases the range of operating conditions.

The following text, in addition to presenting a little of the theoretical background of the orifice meter, also serves to explain the new factors introduced in Section V.

DERIVATION OF THE HYDRAULIC FORMULA

$$s = \sqrt{2g\, h_v} = \sqrt{2g \frac{h}{12} \frac{\gamma_w}{\gamma}} \qquad \text{(I)}$$

$\gamma = \gamma_a\, G \dfrac{P}{14.7} \times \dfrac{492}{T_f}$ Substituting for γ

$$s = \sqrt{2g \frac{h}{12} \frac{\gamma_w}{\gamma_a} \frac{14.7}{492} \frac{T_f}{PG}} = \sqrt{\frac{2 \times 32.16 \times 62.37 \times 14.7\; hT_f}{12 \times .08073 \times 492 \times PG}} \qquad \text{(II)}$$

Reducing to basic conditions, multiplying by the time factor, and by area to obtain volume.

$Q = \dfrac{PT_B}{P_B T_f}\, s \left(\dfrac{3600 \quad \pi d^2}{4 \times 144}\right)$ Substituting for s —

$$Q = \frac{3600\pi}{4 \times 144} \sqrt{\frac{2 \times 32.16 \times 62.37 \times 14.7}{12 \times .08073 \times 492}}\, d^2 \frac{PT_B}{P_B T_f} \sqrt{\frac{hT_f}{PG}}$$

Simplifying and cancelling $\sqrt{\dfrac{T_f}{P}}$

$$Q = 218.44\, d^2 \frac{T_B}{P_B} \sqrt{\frac{hP}{T_f G}} \qquad \text{(III)}$$

For the reasons brought out in the following pages, the experimental value E is brought into the equation, giving the familiar orifice formula $Q = 218.44\, Ed^2 \dfrac{T_B}{P_B} \sqrt{\dfrac{hP}{T_f G}}$ * (IV)

Let $T_B = 520°$ F. absolute.
$T_f = 520°$ F. absolute.
$P_B = 14.4$ lbs. / sq. in absolute.
$G = 1$.

Substituting these values in equation IV.

$Q = 345.92\, Ed^2 \sqrt{hP}$ *

The value of $345.92\, Ed^2$ is the basic orifice coefficient to which correction factors to any set of conditions may be applied.

* NOTE: $S = \dfrac{E\,d^2}{D^2}$. Substitute $\dfrac{SD^2}{d^2}$ in any of the above equations to obtain the working equations used in the preceding sections of Part II.

NOMENCLATURE

NOTE — The standard nomenclature as adopted by the American Society of Mechanical Engineers has been used in so far as it was possible to do so without confliction with terminology of long standing in orifice meter practice.

Symbol		Units
s	= speed of flowing gas at plane of downstream tap	Feet per second
g	= gravitational acceleration (taken as 32.16)	Feet per second per second
D	= diameter of pipe	Inches
P	= absolute pressure of flowing gas	lbs. per sq. in.
T_f	= absolute temperature of flowing gas	Degrees F.
h_v	= height of homogeneous column of gas at P and T_f producing s.	Feet
h	= corresponding height of water column	Inches
γ_w	= density of water (taken as 62.37 at 60° F.).	lbs. per cubic ft.
γa	= density of air (taken as .08073 at 32° F. and 14.7 lbs./sq. in.).	lbs. per cubic ft.
γ	= density of flowing gas.	lbs. per cubic ft.
T_B	= absolute storage temperature on which measurement is based	Degrees F.
P_B	= absolute storage pressure on which measurement is based	lbs. per sq. in.
Q	= volume rate of flow of gas.	Cubic ft. per hr.
G	= specific gravity of flowing gas relative to air	None
E	= ratio of actual to hypothetical flow.	None

Subscript$_1$	Upstream.
Subscript$_2$	Downstream.
Subscript$_f$	Flowing.
Subscript$_B$	Basic.
Subscript$_A$	Actual.
Subscript$_S$	Standard.

APPROXIMATIONS INVOLVED IN EQUATION

$$Q = 218.44\ d^2 \frac{T_B}{P_B}\sqrt{\frac{hP}{T_f G}}$$

The following assumptions are interlinked with the development of the above formula:

1. That the area of the jet at the plane of the downstream pressure tap is that of the orifice.
2. That the velocity of the gas before reaching the orifice is negligible.
3. That the gas does not change appreciably in density in passing through the orifice.
4. That the flow is streamline and frictionless.
5. That the gas follows Boyle's Law.

The major deviations from these assumptions are compensated by the value "E", which is a function of ratio of orifice to pipe diameter. The others are kept negligible in quantitative effect by maintaining operating limits. Manufacturers have taken the maintenance of these limits upon themselves. The effect of change of density between the upstream and downstream connections is, for any one gas and any one ratio of orifice to pipe diameter, dependent on the ratio h/P_2, or some function thereof. The possibility of this deviation ever becoming excessive has been obviated by such means as specification of twenty-inch differential gauges for all types of service requiring continuous operation at or slightly below atmospheric pressure.

Each of the five points outlined above will be discussed in the following pages.

Part II

1. Constriction of Jet

A fluid, in passing through a square sharp edged opening, attains an inward component which reduces the area of the stream to a cross section somewhat less than that of the aperture through which it passes. The effect increases to a point of maximum contraction at the *vena contracta* some distance downstream from the plane of the orifice, and from this point the

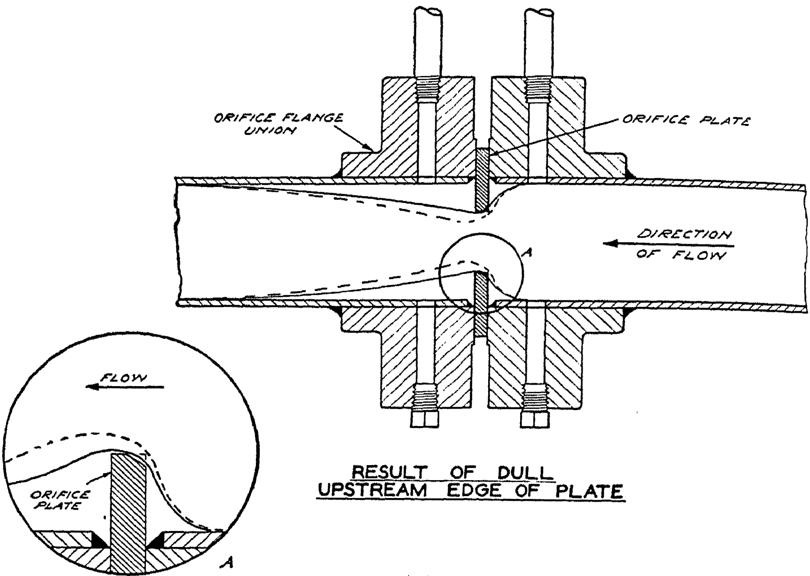
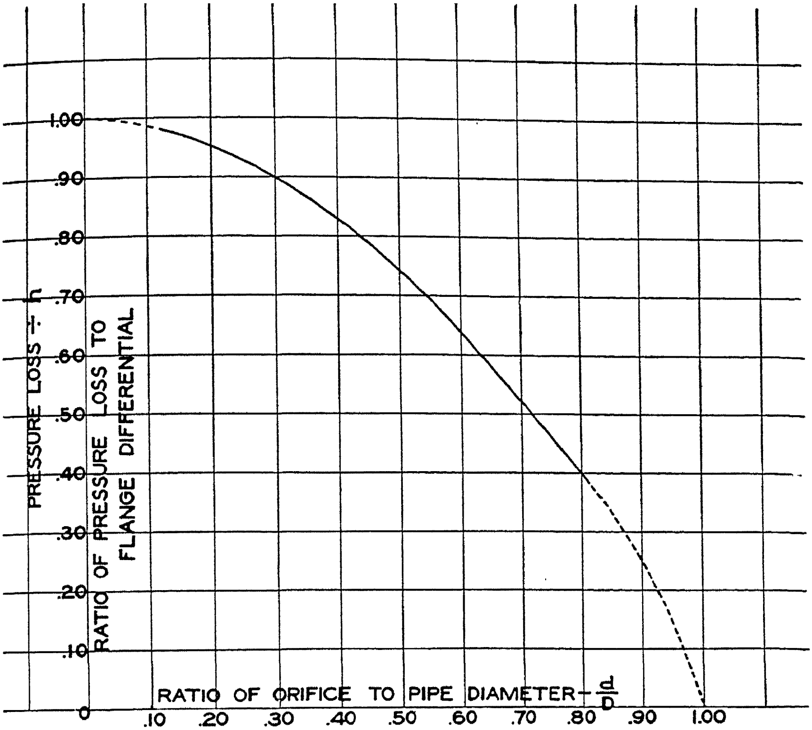


Fig. 7542

fluid gradually resumes the normal flow condition bounded by the walls of the pipe.

The fluid flow from the upstream plane of the orifice is, therefore, convergent, and the jet is more or less independent of the bounding walls of the aperture except at the upstream face. The results obtained with an orifice are, therefore, extremely dependent on the condition of the upstream edge, whereas the

downstream edge is relatively unimportant. The Figure 7542, page 160, illustrates the effect which a rounded upstream edge has upon the ratio of jet to orifice cross section. The result is that the discharge coefficient approaches 1.0. Regarding its



PRESSURE LOSS CURVE
Fig. 2578

effect on measurement, the rounded edge, due to the greater cross section of the jet, permits a greater flow of gas at the same differential pressure.

In order to facilitate duplication of results under all conditions, experimental calibrations were made upon square sharp-

edged orifices; the value of E, among other things, compensates for the exact amount of constriction resulting from the use of this type of orifice.

In resuming normal flow after passing the downstream pressure tap, the gas recovers a certain amount of pressure. As it is often desirable to know the amount of pressure loss resulting from an orifice, the curve shown in Figure 2578, page 161, has been prepared from accurate data on natural gas. The curve shows the ratio of pressure loss at the point of complete recovery to pressure drop between flange connections for various ratios of orifice to pipe diameter. To arrive at the pressure loss in inches of water, multiply the differential pressure shown on the gauge by the factor on the curve corresponding to the ratio of orifice to pipe diameter in use. To convert this pressure loss to its equivalent in pounds per square inch, multiply the result by 0.0361 lbs. per square inch per inch differential.

Pressure taps at other points than at the flange are successfully used in measuring gas flow. The data used in computing the flow are different and as they are dependent upon the positions of the taps, these positions must be known exactly, they must be independent of the human element, they must be independent of variations in downstream line conditions, and they must be exactly duplicable. Great care must be taken that these conditions are complied with.

Summary

1. In order to duplicate the conditions under which coefficients were obtained, the upstream edges of the plates should be square, clean, and sharp.

2. An appreciable increase in pressure from that prevailing at the low pressure flange connection is noticeable downstream, as far as three to eight pipe diameters. The permanent pressure loss is a definite percentage of the differential pressure for any one ratio.

3. Flange connections are recommended because of their reliability, convenience, and high pressure-recovery.

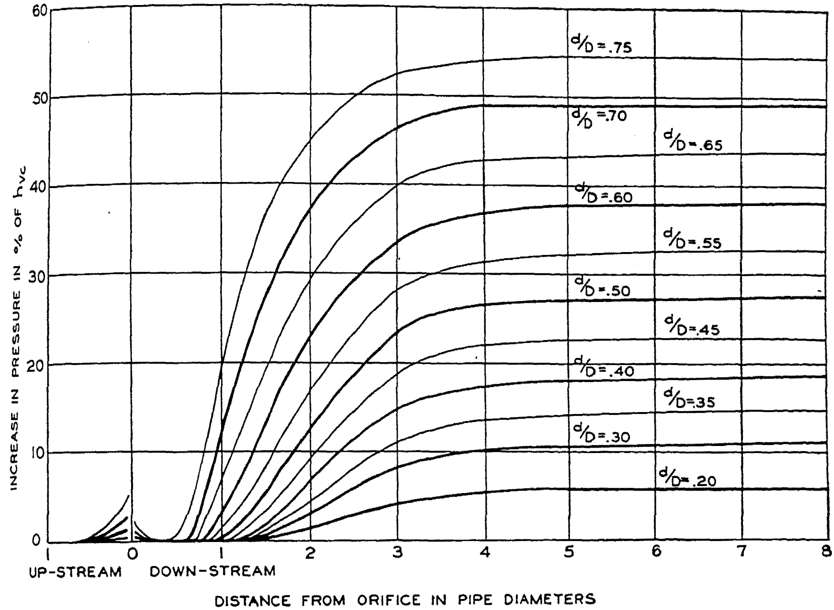


Fig. 8745

Pressure Distribution in the Neighborhood of an Orifice

(Based on Vena Contracta Tap Location and Vena Contracta Differential.)

Compiled by H. J. Cook and D. M. Hill from: Bureau of Standards Research Paper No. 335, and "Fluid Meters, Their Theory and Application" by the American Society of Mechanical Engineers.

Note: h_{vc} = differential pressure (vena contracta taps).

2. Velocity of Approach

The velocity of approach factor is included in the value of "E", and need not be considered in commercial measurement by the orifice type flow meter. It is merely a convenience for the analysis of experimental data and for the comparison of orifice coefficients with flow nozzle and venturi tube data.

If it is assumed that the velocity of the fluid upstream from the orifice is $\frac{d^2}{D^2}$ times that at the plane of the downstream pressure tap, the original formula becomes:

$$s^2 - \left(\frac{d^2}{D^2} s\right)^2 = 2gh$$

$$s = \sqrt{\frac{1}{1 - \left(\frac{d}{D}\right)^4}} \sqrt{2gh}$$

This quantity, $\sqrt{\frac{1}{1 - \left(\frac{d}{D}\right)^4}}$, which is termed the velocity of approach factor, accounts for a great deal of the change in the value of "E". If "E" is equated to $C\sqrt{\frac{1}{1 - \left(\frac{d}{D}\right)^4}}$ and the value of C is plotted against $\frac{d}{D}$, the result is a flat curve with one variable partially eliminated.

Summary

Separate correction need not be made for velocity of approach.

$$\text{NOTE: } d^2\sqrt{\frac{1}{1 - \left(\frac{d}{D}\right)^4}} = D^2\sqrt{\frac{1}{\left(\frac{D}{d}\right)^4 - 1}}$$

3. Change in Density of Compressible Fluids Between Upstream and Downstream Pressure

It may be seen from the analysis of the derivation of the hydraulic formula that it is assumed that the gas does not change in density in passing through the orifice. At extremely low differentials and high pressures, this is approximately true, but, since the medium is compressible, a change in pressure, unless compensated by a change in temperature, must produce a change in density. Actually, both density and temperature decrease with the drop in pressure.

Thermodynamic analysis proves that the influence of change in density upon measurement at any ratio of differential to static pressure varies slightly with the physical characteristics (ratios of specific-heats) of the compressible fluids being measured and with the ratio of orifice to pipe diameter being used.

In Section I, an average correction for the expansion effect is included in the coefficient values and S values, because the method of analysis of the experimental data was such that all deviations from the hydraulic formula were included in the value "E."

In Section V, the basic factors differ from the coefficients in Section I in that the known corrections for expansion factor, Y, were isolated in the analysis of the data, and must, therefore, be applied separately when these basic factors are used.

Expansion Factor, Y

The values listed in the tables are calculated from the following formulae:

$$Y_1 = 1 - \left[0.41 + 0.35\left(\frac{d}{D}\right)^4\right]\frac{x}{k}, \text{ for flange taps.. } \textit{Equation 67}$$

$$Y_1 = 1 - \left[0.333 + 1.145\left(\frac{d^2}{D^2} + 0.7\frac{d^5}{D^5} + 12\frac{d^{13}}{D^{13}}\right)\right]\frac{x}{k}, \text{ for pipe taps. } \textit{Equation 68}$$

$$Y_2 = Y_1\sqrt{\frac{1}{1-x}} \text{ for either flange or pipe taps. . } \textit{Equation 69}$$

3. Flange connections are recommended because of their reliability, convenience, and high pressure-recovery.

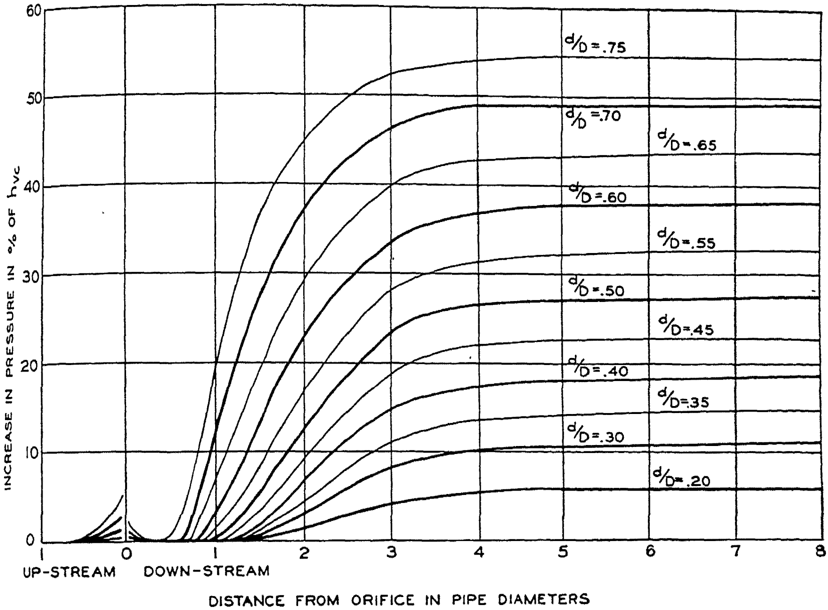


Fig. 8745

Pressure Distribution in the Neighborhood of an Orifice

(Based on Vena Contracta Tap Location and Vena Contracta Differential.)

Compiled by H. J. Cook and D. M. Hill from: Bureau of Standards Research Paper No. 335, and "Fluid Meters, Their Theory and Application" by the American Society of Mechanical Engineers.

Note: h_{vc} = differential pressure (vena contracta taps).

able head of which adds a predetermined percentage of the differential to the downstream pressure.

3. Use of two pressure springs operating a single pen to give a properly weighted average. One spring is attached to the upstream pressure connection and the other to the downstream.

4. Use of a linkage between the differential and static pressure element to increase or decrease the static reading by the desired percent of differential.

5. Use of a special static tap at a point of partial or complete pressure recovery to obtain the desired intermediate pressure. This group includes pitot and venturi statics, which may be used to obtain the required modification of pressures. This classification is of academic interest only, except in special cases.

It is worth noting that a pressure tap at 8 pipe diameters downstream gives the correct intermediate pressure for flange taps on approximately .5 d/D ratio (see Fig. 2578, page 161). This is also the d/D ratio at which the expansion correction is negligible for pipe taps if the static pressure is taken downstream (see page 194).

Minimizing the Expansion Correction

If an intermediate pressure device is not used, the following precautions will minimize the averaging error in the determination of the expansion factor:

1. Use of a low differential range to insure a low h/P ratio at prevailing static pressures.

2. Use of downstream static pressure on 2½ and 8 diameter pipe taps (as well as on flange taps where this procedure is standard practice).

4. Flow Disturbances

(*a*) *Swirls and Eddies*

Fittings or combinations of fittings, which disturb the normal flow of gas, may produce swirls and eddies resulting in a decrease

in differential and a consequent negative error in measurement. In severe instances, it has been found that more than fifty pipe diameters of straight, unobstructed pipe have not been sufficient to completely damp out this condition of flow. Straightening vanes, installed as recommended in the report of The Natural Gas Association of America, eliminate eddies before they reach the point of measurement.

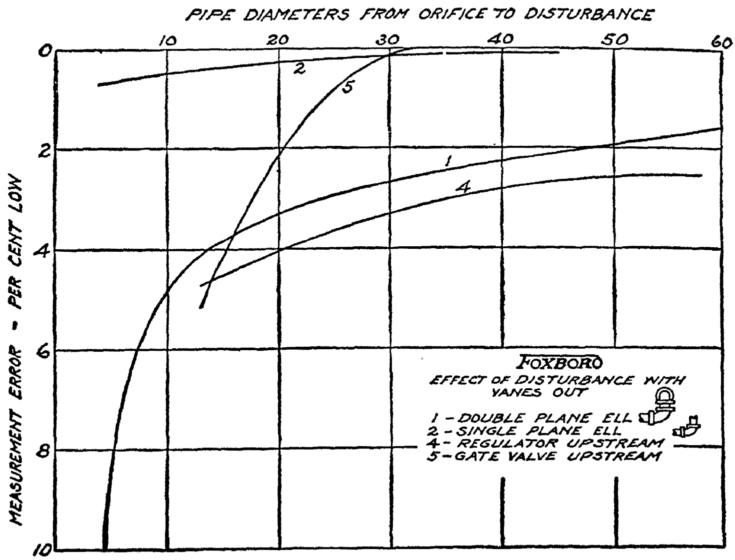


Fig. 4443

Error in measurement due to a swedge is not eliminated by the use of vanes.

Summary

Installations should be made in accordance with limitations outlined in A. G. A. Measurement Committee Report No. 2.

(b) Velocity Distribution Effects

The flow of a fluid under actual line conditions is never uniformly distributed on a traverse. The walls of the pipe have a retarding effect, such that, under ordinary flow conditions above the viscous range, the velocity at the center of the pipe is approximately twenty percent greater than the average throughout the pipe. Any disturbance tending to cause an abnormal centralization of velocity decreases the differential pressure and causes a negative error in measurement; conversely, any disturbance tending to flatten the velocity distribution curve increases the differential pressure and causes a positive error. The effect of false centralization is similar to that of replacing the upstream pipe with one of smaller diameter, in that it increases the velocity of approach and reduces that component of velocity which causes jet constriction. Swedges or orifice plates upstream cause false centralization of velocity. The effect of pipe roughness is slight except on high ratios of orifice to pipe diameter. Straightening vanes, unless designed for a low retarding effect in the central portion, cause an abnormal flattening of the velocity distribution curve. A straight, uninterrupted run of ten diameters of smooth pipe is sufficient to restore normal flow conditions.

(c) Viscous Flow Units

E = ratio of actual to hypothetical flow
d = diameter of orifice . . . . inches
h = differential pressure . . . . inches of water
P = absolute static pressure . . . . . pounds per sq. in.
G = gravity of flowing gas (Air = 1.0)
μ = absolute viscosity of flowing gas . . . . poises*

*Units used in this equation are chosen for convenience; hence the mixture of C.G.S. and English Units. When given viscosity in English units, convert to poises for use in the formula by multiplying by 14.89.

Only at extremely low rates of gas flow are viscosity effects serious sources of inaccuracy. Provided flowing temperature and roughness of pipe remain constant, viscosity deviations from the flow formula on each ratio of orifice to pipe diameter may be plotted against $\frac{E\ d\ \sqrt{h\ P\ G}}{\mu}$ * or any function thereof.

Reynolds Number Factor, F_r.

By the further assumption of constant viscosity and specific gravity for natural gas†, a relationship was developed between viscosity correction factor and values of $\sqrt{hP}$.

It was found that, in the range of operating conditions occurring in natural gas measurement, a simple relationship existed between the viscosity correction factor F_r and $\sqrt{hP}$. This relationship is expressed by the equation $F_r = 1 + \frac{r}{\sqrt{hP}}$, in which "r"‡ is a constant for a given orifice in a given pipe size with a specific pressure tap location.

**NOTE*— E is the ratio of actual rate of flow at conditions of operation to flow indicated by equation $Q = 345.92d^2 \sqrt{\frac{hP}{G}}$. This means that the empirical value of E must be corrected for viscosity, change of density, deviation from Boyle's law, etc., in order to obtain exact results. However, as these corrections are slight, very close approximations may be obtained without applying corrections.

†For other gases, F_r may be computed from the equation

$$F_r = 1 + \frac{r}{\sqrt{hP}} \left(344.2\mu \sqrt{\frac{T}{G}}\right)$$

in which
μ = viscosity in poises
T = absolute temperature (°F. + 460)
G = specific gravity (air = 1.0)

‡The value "r" corresponds to "s" in California Natural Gasoline Association Bulletin TS-353. We regret that interference with existing nomenclature made it impractical to use the same symbol.

Additive Method of Correcting for Reynolds Number

It becomes obvious that this correction is independent of differential and static pressure within the range of operating conditions on which the A.G.A. data is applicable, if the quantity $1 + \frac{r}{\sqrt{hP}}$ is substituted in the complete flow equation. To simplify the subsequent equations, a coefficient omitting F_r is introduced.

$$C'' = F_b \times Y \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \quad . \quad \textit{Equation 72}$$

$$Q = C''F_r \sqrt{hP} = C'' \left(1 + \frac{r}{\sqrt{hP}}\right)\sqrt{hP}$$

$$Q = C''\sqrt{hP} + C''r \quad . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \ . \quad \textit{Equation 73}$$

This additive correction, $C''r$, contains no variables; hence, involves no averaging problem. It is, therefore, an exact correction, regardless of fluctuation of differential and static pressure within the range covered by the A.G.A. data.

The procedure in calculating flows is as follows: Calculate the flow from the formula $Q = C''\sqrt{hP}$, which omits the Reynolds Number correction. If the flow was continuous for a 24-hour period, add to the flow for the day a quantity of gas equal to $24C''r$. In any case, add to the computed flow $nC''r$, in which "n" is the number of hours gas was flowing. It is entirely feasible to make this correction on a weekly or monthly basis.

5. Supercompressibility Factor, F_{pv}.

The supercompressibility factor, F_{pv}, corrects for the deviation from the ideal gas laws which were assumed to hold true in the derivation of the formula. This deviation may be regarded as an additional pressure effect, and correct flows may be obtained by substituting $\frac{\text{"absolute pressure"}}{Z}$ wherever the term pressure appears in the flow calculations. Z is the ratio of theoretical density (calculated from ideal gas laws) to the actual density. The overall effect of this substitution is the factor F_{pv}.

For California natural gas at moderate pressure and atmospheric temperatures, this factor may be read from the C. N. G. A. tables on pages 196 to 206. Where a doubt exists regarding the applica-

bility of these tables to other gases, the supercompressibility should be checked by physical test.

Measurement of Recycle Gas

Operating pressures and temperatures on recycle gas and other extremely high-pressure gas measurements are frequently beyond the range of the C. N. G. A. tables on pages 196 to 206. For these measurements the most reliable means of determining F_{pv} is by calculation from an actual physical test. The supercompressibility characteristics of representative samples of the measured gas are sometimes plotted for future use.

When data on the composition of the gas mixture are available, a satisfactory estimate of the supercompressibility factor may be obtained by application of the theorem of corresponding states. The use of this theorem on gas mixtures requires determination of pseudo-critical temperature and pseudo-critical pressure of the mixture. Pseudo-critical temperature, T_c, of the mixture is calculated by totaling the products of the mol fraction of each constituent times its absolute critical temperature. Pseudo-critical pressure, P_c, is computed in a like manner.

Reduced temperature, T_R, is obtained by dividing the absolute temperature of the gas by the absolute pseudo-critical temperature: $\frac{T}{T_c}$. Reduced pressure, P_R, is obtained by dividing the absolute pressure of the gas by the absolute pseudo-critical pressure: $\frac{P}{P_c}$. Curves showing the value of Z plotted against reduced pressure, P_R, at various values of reduced temperature, T_R, for average natural gas mixtures may be obtained from The Foxboro Company upon request.

For volume measurement

$$F_{pv} = \frac{Z_b}{\sqrt{Z_f}} \quad \text{. . . . .} \quad \textbf{\textit{Equation 74}}$$

in which Z_b = the value taken from the above curves, for base conditions (usually considered 1.0 for natural gas calculations), and Z_f = the value taken from the above curves, for flowing conditions.

When a chemical analysis of the flowing gas is not available, an estimate of the pseudo-critical temperature and pseudo-critical pressure may be obtained from plots of these values against specific gravity. Graphs, based on average natural gas mixtures, may be obtained upon request from The Foxboro Company. The values so obtained are only correct for an assumed average natural gas mixture and should not be used when a more exact method of obtaining F_{pv} is available.

Measurement of Vapors

The measurement of vapors which liquefy near atmospheric conditions may be complicated by a deviation from ideal gas laws at not only flowing conditions, but also at base conditions and at the conditions under which the specific gravity is determined. The formula for pounds of gas per unit of time eliminates the need for base corrections and specific gravity corrections. It is recommended for measurement of chlorine, ammonia, CO_2, and similar vapors. With gas on the surface of the mercury $W^* = 359\ Ed^2 \sqrt{hw}$,

in which W = rate of flow in pounds per hour, w = density of vapor in lbs./cu.ft. at flowing conditions. The value of w for ammonia or CO_2 may be read from tables. For other vapors it may be computed from the equations of Dieterici, Van der Waal, or Berthelot; or, if curves of values of Z are available, may be computed from the formula

$$w = \frac{\text{Molecular Weight}}{10.71} \times \frac{P}{ZT} \quad \text{. . . . . } \textit{Equation 75}$$

in which

P = absolute pressure in lbs./sq. in.,
T = absolute temperature (°F. + 460)

Curves for a number of industrial gases — also equations of Dieterici, Van der Waal, and Berthelot — will be found in Bureau of Standards Circular No. 279, entitled "Relations Between the Temperatures, Pressures and Densities of Gases."

*When using the A.G.A. data as covered in Section V, $W = 1.038\ F_b F_r Y \sqrt{hw}$.

Correction for Displacement of Mercury by High-Pressure Gas or Seal Liquid

When the mercury in a differential gauge is displaced, the fluid which displaces it adds to the differential existing at the orifice, thus causing a float type meter to read high. This effect is so small that it may be neglected on low-pressure gas measurement unless liquid seals are used. At 2100# and 32° F., however, the density of methane is approximately 8.5 lbs./cu.ft., and the effect of this dense gas displacement reduces the coefficient of a mercury float-type meter roughly ½%. A gas of .9 specific gravity at the same temperature and pressure has a density of approximately 22.5 lbs./cu.ft., and this effect reduces the coefficient about 1⅓%. The correction factor by which the coefficient or flow must be multiplied is:

$$B' = \sqrt{\frac{w_m - w_s}{w_m}} = \sqrt{1 - .00118w_s} \quad \ldots\ldots \quad \textit{Equation 76}$$

w_m = density in lbs./cu.ft. of mercury.

w_s = density in lbs./cu.ft. of gas or liquid which displaces the mercury.

B' = flow or coefficient correction factor for displacement of mercury in a float-type differential gauge.

The factor to correct for liquid seals may be calculated from the same formula. When the density of the gas or liquid on the surface of the mercury is known in terms of specific gravity with respect to water at 60° F. the value of B' may be calculated from the table on page 70, using the formula $B' = .9625B$.

PULSATION

The problem of measuring pulsating gas flow is complicated by the presence of reflected pressure waves, differences in timing between wave peaks upstream and downstream from the primary device, and other factors which prevent application of simple mathematical analysis.

A few general rules apply, however. Measurement accuracy may be improved by:

1. Operating at a higher differential; i.e., in a multiple meter run installation, shutting off one or more runs; or installing a smaller orifice in an existing meter run.

2. Installing a higher range differential gauge and changing operating conditions in order to use the increased range.

3. Reducing the pipe run diameter so as to use a higher orifice to pipe diameter ratio, still operating at differentials as high as practicable. Increasing the d/D ratio will reduce the pulsation error if the differential remains constant.

4. Installing mufflers, headers, restrictions, or combinations of capacity and pressure drop between primary device and source of pulsation to reduce pulsation amplitude.

5. Locating the primary device at a point where the pulsation amplitude is lower (as on the suction side of compressors).

The presence or absence of pulsation error may be determined definitely by use of a pulsameter. Measurement within 1% may be obtained at any differential from 20″ to 200″ if the amplitude of the fluctuation in differential is not more than 24%* of operating differential.

The amplitude must be determined by a pulsameter designed to avoid resonant or harmonic vibration effects.

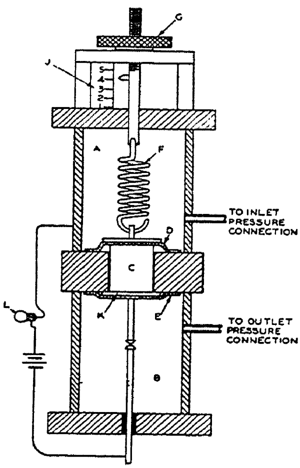
A mechanical pulsameter successfully used in test work is illustrated diagrammatically in Fig. 8675. Two pressure-tight cylinders (A) and (B) are separated by a lightweight piston (C) sealed by two diaphragms (D) and (E). A coil spring (F) may be adjusted in tension by handwheel (G) and an indication of the amount of tension read on scale (J). Any motion of the piston away from the shoulder is indicated by a light (L) operated

*These recommendations are based on the results of three years of test work performed to date under the joint A. G. A. - A. S. M. E. Committee on Pulsation Research.

through contacts located in the low-pressure cylinder (B). The pulsameter is connected across the primary device in the same manner as a flow meter and handwheel (G) adjusted under flowing conditions until the piston is held firmly against shoulder (K). In operation, the tension on the spring is gradually increased until the light goes out and the reading on the scale, taken at that point, represents the peak of the differential pulsation wave. The scale may be calibrated against any differential gauge where no pulsations are present and the results may be plotted or recorded for future use.

The difference between the peak of the differential pulsation wave, determined as described above, and the operating differential as read from the meter is the amplitude of the fluctuation. At 20″ of water differential this should not exceed 24% of the operating differential, and at 200″ it should not exceed 40% of the operating differential for 1% measurement tolerance. These limits apply regardless of the type of pressure taps (flange or pipe) used.

Fig. 8675
PULSAMETER



NOTE: Recent development work has produced a design which it appears will be superior to the above. It employs a metal bellows to replace piston (C) and diaphragms (D) and (E).

SECTION V

American Gas Association
Gas Measurement Committee
Report No. 2

The tables in this section represent the data published in the 1935 report of the Gas Measurement Committee of the American Gas Association. Because of the difficulty of obtaining a properly weighted average of the factors F_r and Y, many methods of application have been devised.

A highly recommended method proposed by the California Natural Gasoline Association is published in their Bulletin TS-402.

Another system, described in detail in the 1939 proceedings of the Appalachian Gas Measurement Short Course, published by the University of West Virginia, Morgantown, W. Va., has been worked out by the Columbia Engineering Corporation, Columbus, Ohio.

Space is not available to enumerate all of the satisfactory methods which have been developed for applying the basic data of A.G.A. Report No. 2. To avoid possibility of measurement discrepancies due to different methods of averaging F_r and Y factors, it is recommended that a method of applying the recommendations of A. G. A. Report No. 2 be settled by advance agreement between the buyer and seller.

For Routine Calculations, use Index, page 212.

Equations

For calculation of the quantity of gas, the following formula is recommended:

$$Q = C'\sqrt{hP} \quad \text{. . . . .} \quad \textit{Equation 77}$$

Q = quantity rate of flow at base conditions, cubic feet per hour.
C′ = corrected orifice flow coefficient, cubic feet per hour.
h = differential pressure in inches water.
P = absolute static pressure in pounds per square inch.

The corrected coefficient, C′, is obtained from the following:

$$C' = F_b \times F_r \times Y \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \quad . \quad \textit{Equation 78}$$

F_b = basic orifice flow factor cubic feet per hour
(Flange taps) see pp. 180 and 182
(Pipe taps) see pp. 188–189

$$F_r = \text{Reynolds number factor} = 1 + \frac{r}{\sqrt{hP}} \quad . \quad \textit{Equation 79}$$

r = a factor used in deriving F_r (Flange taps) see pp. 183-184
(Pipe taps) see pp. 190-191

Y = expansion factor See p. 165

Y_1 = the expansion factor based on the absolute static pressure measured at the upstream connection
(Pipe taps) see pp. 192-193

Y_2 = the expansion factor based on the absolute static pressure measured at the downstream connection (Flange taps) see pp. 185-186
(Pipe taps) see pp. 194-195

F_{gp} = combined factor for specific gravity and pressure base
See pp. 98-102

F_{tb} = temperature base factor See p. 105

F_t = flowing temperature factor See p. 104

F_{pv} = supercompressibility factor See pp. 196-206

F_m = correction for moisture See p. 93

Tables

Tables of $\sqrt{h}$, $\sqrt{P}$, F_{gp}, F_{tb}, and F_t from the preceding sections may be used in the preceding equations. Tables of F_b and Y are reproduced from A. G. A. Gas Measurement Committee Report No. 2. Values of F_r may be interpolated from the formula $F_r = 1 + \frac{r}{\sqrt{hP}}$. Values of r for use in this formula are given for each orifice size with both flange and pipe taps on pages 183 and 190. These values, used in the formula will duplicate the figures in the F_r tables in Report No. 2. A more exact method of applying the Reynolds number correction is the additive method covered by Equation 73, page 171.

The only recognized means of obtaining an accurate supercompressibility factor for natural gas, at the time the A. G. A. supercompressibility tests were performed, was by actual physical test of a sample of the flowing gas. The tables in Report No. 2 were based on this method.

From results of an extensive research program, the California Natural Gasoline Association has since developed an empirical formula which fits the supercompressibility characteristics of California natural gases. The applicability of these findings to natural gas in several other parts of the country has been confirmed by test.* The correction factors, F_{pv}, have been reduced to a convenient set of tables and are reproduced in full on pages 196 to 206 through the courtesy of the California Natural Gasoline Association.

In case of doubt regarding the applicability of these tables to other gases, a representative group of physical tests should be made and compared with results derived from the tables.

*From paper by J. E. Overbeck entitled "Practical Application of A.G.A. Gas Measurement Committee Report No. 2", in 1940 proceedings of the Appalachian Gas Measurement Short Course, the following is quoted: "I am glad to report that the results of these additional tests (78 tests on 47 different gases from fields in the Appalachian area) checked those contained in the California Natural Gasoline Association Bulletin TS-354 well within the limits of accuracy that could be expected from such tests."

A. G. A. Report No. 2 TABLE XXIX

F_b

Basic Orifice Factors — Flange Taps

Base Temperature = 60° F.; Flowing Temperature = 60° F.; $\sqrt{hP} = \infty$;
Base Pressure = 14.4 Lb./Sq. In. abs.; Specific Gravity = 1.0; h/P = 0

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter In.	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
.250	13.002	12.996*	12.974*	....	....	....	....	....
.375	29.079	29.026	28.989*	....	....	....	....	....
.500	51.680	51.444	51.376	51.328*	....	....	....	....
.625	81.129	80.426	80.218	80.080	....	....	....	....
.750	117.77	116.16	115.67	115.30	....	....	....	....
.875	162.11	158.70	157.81	157.08	156.82	....	....	....
1.000	215.04	208.21	206.62	205.45	204.97	....	....	....
1.125	277.93	264.97	262.21	260.39	259.69	259.27	....	....
1.250	353.04	329.41	324.72	321.93	320.94	320.35	320.00	....
1.375	443.44	402.10	394.35	390.11	388.73	387.95	387.47	....
1.500	554.71	483.80	471.35	464.98	463.10	462.07	461.44	....
1.625	....	575.47	556.06	546.62	544.07	542.73	541.93	541.06
1.750	....	678.61	648.93	635.11	631.64	629.94	628.93	627.85
1.875	....	794.99	750.50	730.55	725.90	723.73	722.48	721.15
2.000	....	926.76	861.42	833.06	826.86	824.11	822.56	820.95
2.125	....	1076.6	982.50	942.83	934.59	931.10	929.21	927.26
2.250	....	1251.2	1114.9	1060.0	1049.1	1044.7	1042.4	1040.1
2.375	....	....	1259.9	1184.9	1170.5	1165.1	1162.3	1159.5
2.500	....	....	1419.0	1317.7	1299.0	1292.1	1288.7	1285.4
2.625	....	....	1593.9	1458.7	1434.4	1425.8	1421.7	1417.9
2.750	....	....	1786.7	1608.3	1577.1	1566.4	1561.5	1557.0
2.875	....	....	2000.3	1767.0	1727.1	1713.8	1707.9	1702.6
3.000	....	....	2245.3	1935.2	1884.6	1868.2	1861.0	1854.9
3.125	....	....	....	2113.4	2049.7	2029.5	2020.9	2013.7
3.250	....	....	....	2302.4	2222.7	2197.8	2187.6	2179.2
3.375	....	....	....	2502.8	2403.7	2373.4	2361.1	2351.3
3.500	....	....	....	2715.7	2593.1	2556.1	2541.5	2530.1
3.625	....	....	....	2941.9	2791.1	2746.2	2728.9	2715.6
3.750	....	....	....	3182.5	2998.0	2943.8	2923.2	2907.9
3.875	....	....	....	3438.5	3214.2	3149.1	3124.6	3106.8
4.000	....	....	....	3711.4	3439.9	3362.1	3333.1	3312.5

Note: — Use only nearest 4 significant figures.

*Extrapolated value, $\frac{d}{D}$ less than 0.1.

Continued on page 181

A.G.A. Report No. 2 TABLE XXIX—*Continued*

F_b

BASIC ORIFICE FACTORS — FLANGE TAPS

Base Temperature = 60° F.; Flowing Temperature = 60° F.; $\sqrt{hP} = \infty$;
Base Pressure = 14.4 Lb./Sq. In. abs.; Specific Gravity = 1.0; h/P = 0

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter In.	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
4.250	....	....	....	4313.2	3922.0	3812.1	3772.0	3744.4
4.500	....	....	....	5013.1	4448.7	4295.5	4240.5	4203.8
4.750	....	....	....	....	5024.8	4812.8	4739.6	4691.2
5.000	....	....	....	....	5656.2	5369.9	5270.4	5206.7
5.250	....	....	....	....	6349.6	5965.5	5834.0	5751.2
5.500	....	....	....	....	7112.9	6604.3	6432.1	6324.8
5.750	....	....	....	....	7956.0	7289.8	7066.1	6928.6
6.000	....	....	....	....	8906.5	8026.3	7738.1	7563.0
6.250	....	....	....	....	....	8818.7	8450.0	8229.2
6.500	....	....	....	....	....	9672.0	9204.9	8927.9
6.750	....	....	....	....	....	10592	10006	9660.4
7.000	....	....	....	....	....	11587	10856	10428
7.250	....	....	....	....	....	12664	11759	11231
7.500	....	....	....	....	....	13851	12719	12073
7.750	....	....	....	....	....	....	13741	12954
8.000	....	....	....	....	....	....	14830	13877
8.250	....	....	....	....	....	....	15991	14843
8.500	....	....	....	....	....	....	17231	15856
8.750	....	....	....	....	....	....	18564	16918
9.000	....	....	....	....	....	....	20014	18031
9.250	....	....	....	....	....	....	....	19198
9.500	....	....	....	....	....	....	....	20426
9.750	....	....	....	....	....	....	....	21715
10.000	....	....	....	....	....	....	....	23070
10.250	....	....	....	....	....	....	....	24496
10.500	....	....	....	....	....	....	....	25997
10.750	....	....	....	....	....	....	....	27578
11.000	....	....	....	....	....	....	....	29253
11.250	....	....	....	....	....	....	....	31042

NOTE: — Use only nearest 4 significant figures.

A. G. A. Report No. 2 TABLE XXX

F_b

Basic Orifice Factors — Flange Taps

Base Temperature = 60° F.; Flowing Temperature = 60° F.
Base Pressure = 14.4 lb./sq. in. abs.; Specific Gravity = 1.0

	PIPE SIZES							
Nominal Actual I. D.	2″ XH 1.939″	2″ XXH 1.503″	3″ XH 2.900″	3″ XXH 2.300″	4″ XH 3.826″	4″ XXH 3.152″	6″ XH 5.761″	6″ XXH 4.897″
Orifice dia. in.								
0.250	13.002	13.002	12.996	12.996	....	....	....	....
0.375	29.079	29.171	29.026	29.026	....	....	....	....
0.500	51.745	52.180	51.444	51.581	....	51.476	....	....
0.625	81.329	82.679	80.426	80.826	....	80.438	....	....
0.750	118.27	121.84	116.30	117.08	....	116.10	....	115.44
0.875	163.21	171.51	158.98	160.70	157.93	158.62	....	157.31
1.000	217.33	235.38	208.70	212.19	206.83	208.07	205.57	205.84
1.125	282.33	326.93	265.86	272.57	262.57	264.76	260.56	261.03
1.250	361.72	529.79*	330.91	343.11	325.32	329.02	322.17	322.93
1.375	462.26	....	404.62	425.60	395.28	401.25	390.47	391.79
1.500	602.65*	....	488.08	522.60	472.83	481.83	465.48	467.40
1.625	....	....	582.17	640.47	558.36	572.06	547.33	550.17
1.750	....	....	689.11	788.61*	652.41	673.15	636.11	640.31
1.875	....	....	811.09	999.99*	755.74	786.50	731.95	737.95
2.000	....	....	952.11	1395.44*	868.90	915.42	835.01	843.02
2.125	....	....	1120.1	....	993.04	1061.8	945.48	956.93
2.250	....	....	1328.4*	....	1130.0	1231.0	1063.6	1079.2
2.375	....	....	....	....	1280.4	....	1189.7	1210.4
2.500	....	....	....	....	1448.0	....	1324.0	1351.1
2.625	....	....	....	....	1633.9	....	1466.9	1503.7
2.750	....	....	....	....	1842.7	....	1618.8	1667.9
2.875	....	....	....	....	2077.6*	....	1780.4	1843.0
3.000	....	....	....	....	....	....	1952.4	2032.2
3.125	....	....	....	....	....	....	2135.4	2235.4
3.250	....	....	....	....	....	....	2330.0	2460.7
3.375	....	....	....	....	....	....	2536.8	2697.8
3.500	....	....	....	....	....	....	2758.0	2963.7
3.625	....	....	....	....	....	....	2993.9	3253.1
3.750	....	....	....	....	....	....	3245.5	3582.5*
3.875	....	....	....	....	....	....	3514.5	3965.7*
4.000	....	....	....	....	....	....	3802.6	....
4.250	....	....	....	....	....	....	4456.6	....

$\frac{d}{D}$ greater than 75 percent.

Note: — Use only nearest 4 significant figures.

From "Orifice Coefficients for Thick Wall High Pressure Piping," by D. A. Sillers, *The Petroleum Engineer*, February, 1941.

A. G. A. Report No. 2 TABLE XXXI

Flange Connections

Values of r in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$

Orifice dia. in.	Nominal Pipe Size							
	2″	3″	4″	6″	8″	10″	12″	15¼″
.250	.0927	.1010	.1055	....	....	....	....	....
.375	.0725	.0836	.0907	....	....	....	....	....
.500	.0588	.0695	.0780	.0892	....	....	....	....
.625	.0505	.0584	.0669	.0801	....	....	....	....
.750	.0472	.0500	.0578	.0711	....	....	....	....
.875	.0476	.0438	.0502	.0644	.0741	....	....	....
1.000	.0515	.0438	.0441	.0576	.0680	....	....	....
1.125	.0575	.0385	.0396	.0516	.0623	.0705	....	....
1.250	.0645	.0388	.0365	.0464	.0572	.0656	.0720	....
1.375	.0716	.0407	.0345	.0420	.0524	.0612	.0676	....
1.500	.0773	.0436	.0338	.0381	.0479	.0568	.0636	....
1.625	....	.0476	.0339	.0348	.0440	.0528	.0597	.0684
1.750	....	.0523	.0351	.0324	.0404	.0489	.0561	.0652
1.875	....	.0574	.0369	.0302	.0371	.0456	.0527	.0619
2.000	....	.0623	.0396	.0288	.0343	.0424	.0493	.0587
2.125	....	.0669	.0427	.0279	.0320	.0393	.0464	.0557
2.250	....	.0708	.0464	.0273	.0296	.0365	.0435	.0529
2.375	....	....	.0502	.0276	.0280	.0340	.0407	.0503
2.500	....	....	.0540	.0279	.0264	.0320	.0383	.0476
2.625	....	....	.0579	.0287	.0255	.0299	.0360	.0452
2.750	....	....	.0616	.0299	.0245	.0280	.0336	.0428
2.875	....	....	.0648	.0315	.0240	.0265	.0316	.0407
3.000	....	....	0.673	.0332	.0237	.0252	.0299	.0385
3.125	....	....	....	.0353	.0237	.0238	.0281	.0364
3.250	....	....	....	.0376	.0240	.0231	.0267	.0347
3.375	....	....	....	.0400	.0244	.0224	.0253	.0328
3.500	....	....	....	.0425	.0252	.0217	.0241	.0312
3.625	....	....	....	.0452	.0260	.0215	.0231	.0296
3.750	....	....	....	.0479	.0272	.0212	.0220	.0280
3.875	....	....	....	.0504	.0284	.0211	.0213	.0267

Note: Calculate F_r to only nearest 4 significant figures

Continued on page 184

A. G. A. Report No. 2 TABLE XXXI — *Continued*

FLANGE CONNECTIONS

Values of r in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$

Orifice dia. in.	Nominal Pipe Size 2″	3″	4″	6″	8″	10″	12″	15¼″
4.000	....	....	....	.0532	.0297	.0212	.0207	.0256
4.250	....	....	....	.0580	.0328	.0220	.0197	.0232
4.500	....	....	....	.0620	.0365	.0231	.0193	.0213
4.750	....	....	....	....	.0405	.0248	.0195	.0200
5.000	....	....	....	....	.0447	.0272	.0200	.0187
5.250	....	....	....	....	.0487	.0296	.0208	.0180
5.500	....	....	....	....	.0525	.0324	.0220	.0175
5.750	....	....	....	....	.0560	.0353	.0237	.0172
6.000	....	....	....	....	.0588	.0385	.0256	.0174
6.250	....	....	....	....	....	.0420	.0276	.0176
6.500	....	....	....	....	....	.0452	.0300	.0185
6.750	....	....	....	....	....	.0483	.0325	.0192
7.000	....	....	....	....	....	.0513	.0352	.0204
7.250	....	....	....	....	....	.0540	.0380	.0216
7.500	....	....	....	....	....	.0565	.0407	.0231
7.750	....	....	....	....	....	....	.0433	.0247
8.000	....	....	....	....	....	....	.0460	.0264
8.250	....	....	....	....	....	....	.0487	.0284
8.500	....	....	....	....	....	....	.0512	.0304
8.750	....	....	....	....	....	....	.0533	.0324
9.000	....	....	....	....	....	....	.0553	.0347
9.250	....	....	....	....	....	....	....	.0368
9.500	....	....	....	....	....	....	....	.0392
9.750	....	....	....	....	....	....	....	.0412
10.000	....	....	....	....	....	....	....	.0433
10.250	....	....	....	....	....	....	....	.0455
10.500	....	....	....	....	....	....	....	.0476
10.750	....	....	....	....	....	....	....	.0496
11.000	....	....	....	....	....	....	....	.0513
11.250	....	....	....	....	....	....	....	.0529

NOTE: Calculate F_r to only nearest 4 significant figures

A. G. A. Report No. 2 TABLE XXXII

Y_2

Expansion Factors — Flange Taps
Static Pressure Taken from Downstream Tap

Line Size	ORIFICE SIZES												
	1/8" 1/4"	3/8" 1/2"	5/8"	3/4"	7/8"	1"		1 1/8"				1 1/4"	
	1/8" 3/8"	1/2" 3/4"	7/8" 1"	1 1/8" 1 1/4"	1 3/8"	1 1/2"		1 5/8"		1 3/4"		1 7/8"	
	1/8" 1/2"	5/8" 1"	1 1/8" 1 3/8"	1 1/2" 1 5/8"	1 3/4" 1 7/8"	2"	2 1/8"		2 1/4"	2 3/8"			2 1/2"
	1/8" 7/8"	1" 1 1/2"	1 5/8" 2"	2 1/8" 2 1/2"	2 5/8" 2 7/8"	3"	3 1/8"	3 1/4"	3 3/8"	3 1/2"	3 5/8"		3 3/4"
	1/8" 1 1/8"	1 1/4" 2"	2 1/4" 2 3/4"	2 7/8" 3 3/8"	3 1/2" 3 3/4"	3 7/8" 4"	4 1/4"		4 1/2"	4 3/4"			5"
10"	1/8" 1 1/2"	1 5/8" 2 1/2"	2 5/8" 3 1/2"	3 5/8" 4 1/4"	4 1/2" 4 3/4"	5"	5 1/4"	5 1/2"	5 3/4"		6"		6 1/4"
12"	1/8" 1 3/4"	1 7/8" 3"	3 1/8" 4"	4 1/4" 5"	5 1/4" 5 1/2	5 3/4" 6"	6 1/4"	6 1/2"	6 3/4"	7"	7 1/4"		7 1/2"
15 1/4"	1/8" 2 1/4"	2 1/2" 3 3/4"	3 7/8" 5 1/4"	5 1/2" 6 1/4"	6 1/2" 7 1/4"	7 1/2" 7 3/4"	8"	8 1/4"	8 1/2"	8 3/4"	9"	9 1/4"	9 1/2"

$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio												
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60	.61	.62
0.1	1.0007	1.0007	1.0007	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0006	1.0005	1.0005	1.0005
0.2	1.0013	1.0013	1.0013	1.0013	1.0013	1.0012	1.0012	1.0012	1.0012	1.0011	1.0011	1.0011	1.0011
0.3	1.0020	1.0020	1.0020	1.0020	1.0019	1.0018	1.0018	1.0018	1.0017	1.0017	1.0016	1.0016	1.0016
0.4	1.0027	1.0027	1.0027	1.0026	1.0026	1.0025	1.0024	1.0024	1.0023	1.0023	1.0022	1.0022	1.0021
0.5	1.0033	1.0033	1.0033	1.0032	1.0031	1.0030	1.0029	1.0029	1.0028	1.0028	1.0027	1.0027	1.0027
0.6	1.0040	1.0040	1.0040	1.0039	1.0038	1.0036	1.0036	1.0035	1.0034	1.0033	1.0032	1.0032	1.0031
0.7	1.0047	1.0047	1.0047	1.0045	1.0044	1.0043	1.0042	1.0041	1.0040	1.0039	1.0038	1.0038	1.0037
0.8	1.0053	1.0053	1.0053	1.0051	1.0050	1.0049	1.0048	1.0047	1.0046	1.0045	1.0044	1.0043	1.0043
0.9	1.0060	1.0060	1.0060	1.0058	1.0057	1.0055	1.0051	1.0053	1.0052	1.0050	1.0049	1.0048	1.0048
1.0	1.0067	1.0066	1.0065	1.0064	1.0063	1.0061	1.0060	1.0059	1.0058	1.0056	1.0055	1.0054	1.0053
1.1	1.0074	1.0073	1.0073	1.0071	1.0069	1.0067	1.0066	1.0065	1.0063	1.0061	1.0060	1.0059	1.0058
1.2	1.0080	1.0080	1.0079	1.0077	1.0075	1.0073	1.0072	1.0071	1.0069	1.0067	1.0066	1.0065	1.0064
1.3	1.0087	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0077	1.0075	1.0073	1.0071	1.0070	1.0069
1.4	1.0094	1.0093	1.0093	1.0091	1.0088	1.0086	1.0084	1.0083	1.0081	1.0079	1.0077	1.0076	1.0074
1.5	1.0100	1.0100	1.0099	1.0097	1.0094	1.0091	1.0090	1.0088	1.0086	1.0084	1.0082	1.0081	1.0080
1.6	1.0108	1.0107	1.0106	1.0104	1.0101	1.0097	1.0097	1.0095	1.0093	1.0090	1.0088	1.0086	1.0085
1.7	1.0114	1.0114	1.0113	1.0110	1.0108	1.0104	1.0103	1.0101	1.0099	1.0096	1.0094	1.0092	1.0091
1.8	1.0121	1.0120	1.0120	1.0117	1.0114	1.0110	1.0108	1.0106	1.0104	1.0102	1.0100	1.0097	1.0096
1.9	1.0128	1.0127	1.0126	1.0123	1.0120	1.0116	1.0115	1.0112	1.0110	1.0107	1.0104	1.0103	1.0101
2.0	1.0134	1.0133	1.0132	1.0129	1.0126	1.0122	1.0121	1.0118	1.0116	1.0113	1.0110	1.0108	1.0106
2.1	1.0140	1.0149	1.0139	1.0136	1.0133	1.0129	1.0127	1.0124	1.0122	1.0119	1.0115	1.0114	1.0111
2.2	1.0147	1.0147	1.0146	1.0142	1.0139	1.0135	1.0133	1.0130	1.0128	1.0125	1.0121	1.0120	1.0118
2.3	1.0151	1.0151	1.0153	1.0149	1.0146	1.0141	1.0139	1.0136	1.0133	1.0130	1.0127	1.0125	1.0123
2.4	1.0160	1.0160	1.0159	1.0155	1.0151	1.0146	1.0144	1.0141	1.0138	1.0135	1.0133	1.0130	1.0128
2.5	1.0167	1.0167	1.0166	1.0162	1.0158	1.0153	1.0150	1.0148	1.0145	1.0141	1.0137	1.0135	1.0133
2.6	1.0174	1.0173	1.0172	1.0168	1.0161	1.0159	1.0156	1.0151	1.0151	1.0147	1.0143	1.0141	1.0139
2.7	1.0183	1.0182	1.0181	1.0176	1.0172	1.0167	1.0164	1.0161	1.0158	1.0154	1.0150	1.0148	1.0146
2.8	1.0187	1.0186	1.0185	1.0180	1.0176	1.0171	1.0168	1.0165	1.0162	1.0158	1.0154	1.0152	1.0149
2.9	1.0194	1.0194	1.0192	1.0187	1.0183	1.0177	1.0175	1.0172	1.0168	1.0164	1.0160	1.0157	1.0155
3.0	1.0200	1.0200	1.0198	1.0193	1.0189	1.0183	1.0180	1.0177	1.0173	1.0169	1.0165	1.0162	1.0160
3.1	1.0207	1.0206	1.0205	1.0200	1.0195	1.0189	1.0186	1.0183	1.0179	1.0175	1.0171	1.0168	1.0166
3.2	1.0213	1.0213	1.0211	1.0206	1.0201	1.0195	1.0192	1.0189	1.0185	1.0180	1.0176	1.0173	1.0171
3.3	1.0220	1.0220	1.0218	1.0213	1.0208	1.0202	1.0198	1.0195	1.0191	1.0186	1.0181	1.0178	1.0176
3.4	1.0227	1.0227	1.0225	1.0219	1.0214	1.0208	1.0205	1.0201	1.0197	1.0192	1.0187	1.0184	1.0182
3.5	1.0233	1.0233	1.0231	1.0225	1.0220	1.0214	1.0210	1.0207	1.0202	1.0198	1.0192	1.0190	1.0187
3.6	1.0240	1.0239	1.0237	1.0232	1.0227	1.0220	1.0216	1.0212	1.0208	1.0203	1.0198	1.0195	1.0192
3.7	1.0246	1.0246	1.0244	1.0238	1.0232	1.0225	1.0221	1.0217	1.0213	1.0208	1.0203	1.0200	1.0197
3.8	1.0252	1.0252	1.0250	1.0244	1.0238	1.0231	1.0227	1.0223	1.0219	1.0214	1.0209	1.0206	1.0203
3.9	1.0259	1.0259	1.0257	1.0250	1.0245	1.0237	1.0234	1.0229	1.0225	1.0220	1.0214	1.0211	1.0208
4.0	1.0265	1.0265	1.0263	1.0256	1.0251	1.0243	1.0240	1.0235	1.0231	1.0225	1.0220	1.0217	1.0213

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30.
Use only nearest 4 significant figures.

Continued on page 186

$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio												
	.63	.64	.65	.66	.67	.68	.69	.70	.71	.72	.73	.74	.75
0.1	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0005	1.0004	1.0004	1.0004	1.0004	1.0004	1.0004
0.2	1.0010	1.0010	1.0010	1.0010	1.0009	1.0009	1.0009	1.0009	1.0008	1.0008	1.0008	1.0008	1.0007
0.3	1.0016	1.0015	1.0015	1.0015	1.0014	1.0014	1.0014	1.0013	1.0013	1.0012	1.0012	1.0011	1.0011
0.4	1.0021	1.0021	1.0020	1.0020	1.0019	1.0019	1.0018	1.0018	1.0017	1.0017	1.0016	1.0015	1.0015
0.5	1.0026	1.0026	1.0025	1.0025	1.0024	1.0024	1.0023	1.0022	1.0022	1.0021	1.0020	1.0019	1.0019
0.6	1.0031	1.0030	1.0030	1.0029	1.0028	1.0027	1.0027	1.0026	1.0025	1.0024	1.0023	1.0022	1.0022
0.7	1.0036	1.0035	1.0035	1.0034	1.0033	1.0032	1.0031	1.0031	1.0030	1.0029	1.0028	1.0026	1.0025
0.8	1.0042	1.0041	1.0040	1.0039	1.0038	1.0037	1.0036	1.0035	1.0034	1.0033	1.0032	1.0031	1.0029
0.9	1.0047	1.0046	1.0045	1.0043	1.0042	1.0041	1.0040	1.0039	1.0039	1.0037	1.0036	1.0035	1.0033
1.0	1.0052	1.0051	1.0050	1.0049	1.0048	1.0046	1.0045	1.0044	1.0043	1.0041	1.0040	1.0039	1.0037
1.1	1.0057	1.0056	1.0055	1.0054	1.0053	1.0051	1.0050	1.0049	1.0047	1.0046	1.0044	1.0042	1.0040
1.2	1.0062	1.0061	1.0060	1.0059	1.0057	1.0056	1.0054	1.0053	1.0051	1.0050	1.0048	1.0046	1.0044
1.3	1.0067	1.0066	1.0065	1.0064	1.0062	1.0061	1.0060	1.0058	1.0056	1.0054	1.0052	1.0050	1.0048
1.4	1.0073	1.0072	1.0070	1.0069	1.0067	1.0065	1.0063	1.0062	1.0060	1.0058	1.0056	1.0054	1.0052
1.5	1.0078	1.0077	1.0075	1.0074	1.0072	1.0070	1.0068	1.0067	1.0065	1.0063	1.0060	1.0058	1.0056
1.6	1.0083	1.0081	1.0080	1.0078	1.0076	1.0075	1.0073	1.0071	1.0069	1.0066	1.0064	1.0062	1.0059
1.7	1.0089	1.0087	1.0086	1.0084	1.0082	1.0080	1.0078	1.0076	1.0074	1.0071	1.0069	1.0066	[illegible]
1.8	1.0094	1.0092	1.0090	1.0089	1.0087	1.0084	1.0082	1.0080	1.0078	1.0075	1.0073	1.0070	1.0067
1.9	1.0099	1.0097	1.0095	1.0093	1.0091	1.0089	1.0087	1.0084	1.0082	1.0079	1.0077	1.0074	1.0071
2.0	1.0104	1.0202	1.0030	1.0098	1.0096	1.0094	1.0092	1.0089	1.0087	1.0084	1.0081	1.0078	1.0075
2.1	1.0110	1.0108	1.0105	1.0103	1.0161	1.0099	1.0096	1.0094	1.0091	1.0088	1.0085	1.0082	1.0079
2.2	1.0115	1.0114	1.0111	1.0109	1.0107	1.0104	1.0101	1.0098	1.0095	1.0094	1.0089	1.0086	1.0083
2.3	1.0121	1.0119	1.0116	1.0114	1.0111	1.0109	1.0106	1.0103	1.0100	1.0097	1.0095	1.0090	1.0086
2.4	1.0126	1.0124	1.0121	1.0119	1.0116	1.0113	1.0111	1.0108	1.0105	1.0102	1.0098	1.0095	1.0091
2.5	1.0131	1.0128	1.0126	1.0123	1.0120	1.0118	1.0115	1.0112	1.0109	1.0106	1.0102	1.0098	1.0094
2.6	1.0136	1.0134	1.0131	1.0128	1.0125	1.0123	1.0120	1.0116	1.0113	1.0110	1.0106	1.0102	1.0099
2.7	1.0143	1.0141	1.0138	1.0135	1.0132	1.0129	1.0126	1.0123	1.0119	1.0115	1.0111	1.0107	1.0103
2.8	1.0147	1.0144	1.0141	1.0138	1.0134	1.0132	1.0128	1.0126	1.0122	1.0118	1.0114	1.0110	1.0106
2.9	1.0152	1.0150	1.0147	1.0144	1.0141	1.0137	1.0134	1.0131	1.0127	1.0123	1.0119	1.0114	1.0110
3.0	1.0157	1.0155	1.0152	1.0149	1.0146	1.0142	1.0139	1.0135	1.0131	1.0127	1.0123	1.0119	1.0114
3.1	1.0163	1.0160	1.0157	1.0153	1.0150	1.0147	1.0143	1.0139	1.0135	1.0131	1.0127	1.0123	1.0118
3.2	1.0168	1.0165	1.0162	1.0158	1.0155	1.0152	1.0148	1.0144	1.0140	1.0136	1.0131	1.0127	1.0122
3.3	1.0173	[illegible]	1.0166	1.0163	1.0159	[illegible]	[illegible]	1.0148	[illegible]	1.0139	[illegible]	[illegible]	1.0125
3.4	1.0179	1.0175	1.0172	[illegible]	1.0165	[illegible]	[illegible]	1.0153	[illegible]	[illegible]	[illegible]	1.0135	1.0129
3.5	1.0183	1.0180	1.0177	1.0173	[illegible]	1.0165	1.0161	1.0157	1.0153	[illegible]	1.0145	1.0139	1.0133
3.6	1.0188	1.0185	1.0182	1.0178	1.0174	1.0170	1.0166	1.0162	1.0158	1.0153	1.0148	1.0143	1.0138
3.7	1.0193	1.0190	1.0187	1.0183	1.0179	1.0175	1.0171	1.0167	1.0162	[illegible]	[illegible]	[illegible]	1.0141
3.8	1.0199	1.0196	1.0192	1.0188	1.0185	1.0180	1.0176	1.0172	1.0167	1.0162	[illegible]	1.0151	1.0145
3.9	1.0205	1.0201	1.0197	1.0193	1.0189	1.0185	1.0180	1.0175	1.0171	1.0166	[illegible]	[illegible]	1.0149
4.0	1.0210	1.0206	1.0202	1.0198	1.0194	1.0190	1.0185	1.0180	1.0175	1.0174	1.0169	1.0157	1.0153

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30

Fig. 8744
Foxboro Flow Meters in a gasoline plant in Texas

A.G.A. Report No. 2 TABLE XXXIII

F_b

Basic Orifice Factors — Pipe Taps

Base Temperature = 60° F. Flowing Temperature = 60° F.; $\sqrt{hP} = \infty$;
Base Pressure = 14.4 Lb./Sq. In. abs.; Specific Gravity = 1.0; h/P = 0.

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter In.	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
.250	13.093	13.040*	13.014*	....	....	....	....	....
.375	29.670	29.339	29.239*	....	....	....	....	....
.500	53.684	52.417	52.052	51.788*	....	....	....	....
.625	86.010	82.687	81.664	80.977	....	....	....	....
.750	127.85	120.70	118.38	116.82	....	....	....	....
.875	181.14	167.05	162.58	159.46	158.52	....	....	....
1.000	248.85	222.51	214.72	209.09	207.40	....	....	....
1.125	335.50	288.12	275.26	265.94	263.09	261.83	....	....
1.250	448.03	365.31	344.77	330.26	325.74	323.74	322.73	....
1.375	597.35	455.95	424.00	402.34	395.48	392.47	390.97	....
1.500	....	562.54	513.89	482.50	472.51	468.12	465.95	....
1.625	....	688.37	615.59	571.03	557.01	550.80	547.75	545.14
1.750	....	837.81	730.52	668.30	649.20	640.64	636.46	632.90
1.875	....	1016.8	860.47	774.75	749.31	737.80	732.17	727.42
2.000	....	1233.2	1007.6	890.89	857.57	842.42	835.00	828.76
2.125	....	1498.7	1174.7	1017.3	974.22	954.67	945.05	936.97
2.250	....	....	1365.0	1154.7	1099.5	1074.7	1062.4	1052.1
2.375	....	....	1582.8	1303.8	1233.8	1202.8	1187.3	1174.4
2.500	....	....	1833.4	1465.6	1377.3	1339.0	1319.8	1303.7
2.625	....	....	2123.5	1641.0	1530.6	1483.6	1460.1	1440.2
2.750	....	....	2462.2	1831.3	1694.1	1636.7	1608.2	1584.1
2.875	....	....	....	2037.9	1868.1	1798.7	1764.5	1735.3
3.000	....	....	....	2262.3	2053.4	1969.7	1928.9	1894.1
3.125	....	....	....	2506.3	2250.4	2150.1	2101.8	2060.5
3.250	....	....	....	2772.0	2459.8	2340.2	2283.2	2234.6
3.375	....	....	....	3061.9	2682.5	2540.3	2473.4	2416.5
3.500	....	....	....	3378.7	2919.1	2750.8	2672.5	2606.5
3.625	....	....	....	3725.7	3170.6	2972.1	2880.8	2804.5
3.750	....	....	....	4106.8	3437.6	3204.6	3098.7	3010.7
3.875	....	....	....	4526.5	3722.6	3448.8	3326.2	3225.3
4.000	....	....	....	4990.2	4025.4	3705.2	3563.8	3448.4

Note: — Use only nearest 4 significant figures.

*Extrapolated value, $\frac{d}{D}$ less than 0.1.

Continued on page 189

A.G.A. Report No. 2 TABLE XXXIII — *Continued*

F_b

BASIC ORIFICE FACTORS — PIPE TAPS

Base Temperature = 60° F. Flowing Temperature = 60° F.; $\sqrt{hP} = \infty$;
Base Pressure = 14.4 Lb./Sq. In. abs.; Specific Gravity = 1.0; h/P = 0.

Pipe Sizes — Nominal and Actual Diameters

Orifice Diameter In.	2″ Std. 2.067	3″ Std. 3.068	4″ Std. 4.026	6″ Std. 6.065	8″ Std. 8.071	10″ Std. 10.136	12″ Std. 12.090	15¼″ Std. 15.25
4.250	....	....	....	....	4691.8	4257.0	4070.2	3920.7
4.500	....	....	....	....	5450.1	4865.1	4620.6	4428.8
4.750	....	....	....	....	6316.8	5530.7	5218.3	4974.3
5.000	....	....	....	....	7312.5	6275.5	5866.8	5558.9
5.250	....	....	....	....	8463.7	7093.4	6570.4	6184.4
5.500	....	....	....	....	9804.8	7999.2	7333.7	6853.0
5.750	....	....	....	....	....	9004.9	8162.4	7566.9
6.000	....	....	....	....	....	10125	9062.8	8328.8
6.250	....	....	....	....	....	11376	10042	9141.8
6.500	....	....	....	....	....	12779	11109	10009
6.750	....	....	....	....	....	14360	12273	10934
7.000	....	....	....	....	....	16152	13545	11921
7.250	....	....	....	....	....	....	14939	12974
7.500	....	....	....	....	....	....	16470	14099
7.750	....	....	....	....	....	....	18157	15301
8.000	....	....	....	....	....	....	20020	16587
8.250	....	....	....	....	....	....	22088	17964
8.500	....	....	....	....	....	....	....	19439
8.750	....	....	....	....	....	....	....	21022
9.000	....	....	....	....	....	....	....	22723
9.250	....	....	....	....	....	....	....	24553
9.500	....	....	....	....	....	....	....	26526
9.750	....	....	....	....	....	....	....	28656
10.000	....	....	....	....	....	....	....	30962
10.250	....	....	....	....	....	....	....	33462
10.500	....	....	....	....	....	....	....	36182

NOTE: — Use only nearest 4 significant figures.

A.G.A. Report No. 2 TABLE XXXIV

PIPE TAPS

2½ and 8

Values of r in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$

Orifice Dia. In.	Nominal Pipe Size							
	2″	3″	4″	6″	8″	10″	12″	15¼″
.250	.1087	.1083	.1092	....	....	....	....	....
.375	.0876	.0904	.0940	....	....	....	....	....
.500	.0728	.0760	.0810	.0886	....	....	....	....
.625	.0636	.0641	.0696	.0803	....	....	....	....
.750	.0585	.0552	.0601	.0720	....	....	....	....
.875	.0572	.0488	.0524	.0641	.0733	....	....	....
1.000	.0576	.0445	.0460	.0573	.0672	....	....	....
1.125	.0596	.0424	.0413	.0512	.0613	.0695	....	....
1.250	.0616	.0413	.0377	.0459	.0559	.0645	.0709	....
1.375	.0632	.0420	.0353	.0414	.0511	.0597	.0665	....
1.500	....	.0432	.0340	.0372	.0466	.0555	.0625	....
1.625	....	.0448	.0338	.0339	.0425	.0513	.0585	.0676
1.750	....	.0472	.0340	.0312	.0387	.0475	.0548	.0641
1.875	....	.0493	.0349	.0289	.0355	.0440	.0513	.0610
2.000	....	.0508	.0363	.0273	.0327	.0408	.0480	.0579
2.125	....	.0519	.0379	.0262	.0301	.0376	.0449	.0548
2.250	....	....	.0398	.0256	.0280	.0349	.0419	.0520
2.375	....	....	.0417	.0253	.0261	.0325	.0392	.0493
2.500	....	....	.0436	.0255	.0247	.0301	.0367	.0465
2.625	....	....	.0451	.0259	.0233	.0280	.0342	.0440
2.750	....	....	.0464	.0264	.0224	.0263	.0320	.0417
2.875	....	....	....	.0273	.0218	.0247	.0299	.0393
3.000	....	....	....	.0285	.0213	.0232	.0280	.0372
3.125	....	....	....	.0297	.0211	.0221	.0264	.0352
3.250	....	....	....	.0311	.0211	.0211	.0249	.0333
3.375	....	....	....	.0325	.0215	.0203	.0235	.0315
3.500	....	....	....	.0339	.0217	.0197	.0223	.0298
3.625	....	....	....	.0354	.0224	.0191	.0212	.0282
3.750	....	....	....	.0368	.0231	.0189	.0202	.0267
3.875	....	....	....	.0381	.0239	.0187	.0193	.0253

NOTE: Calculate F_r to only nearest 4 significant figures

Continued on page 191

A. G. A. Report No. 2 TABLE XXXIV — *Continued*

Pipe Taps

2½ and 8

Values of r in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$

Orifice Dia. In.	Nominal Pipe Size 2″	3″	4″	6″	8″	10″	12″	15¼″
4.000	....	....	....	.0392	.0248	.0187	.0188	.0240
4.250	....	....	....	....	.0269	.0189	.0176	.0216
4.500	....	....	....	....	.0291	.0197	.0171	.0200
4.750	....	....	....	....	.0315	.0208	.0169	.0184
5.000	....	....	....	....	.0336	.0221	.0172	.0172
5.250	....	....	....	....	.0356	.0240	.0178	.0162
5.500	....	....	....	....	.0373	.0258	.0186	.0156
5.750	....	....	....	....	....	.0276	.0196	.0153
6.000	....	....	....	....	....	.0296	.0211	.0152
6.250	....	....	....	....	....	.0313	.0224	.0154
6.500	....	....	....	....	....	.0331	.0240	.0159
6.750	....	....	....	....	....	.0347	.0255	.0164
7.000	....	....	....	....	....	.0360	.0272	.0172
7.250	....	....	....	....	....	....	.0288	.0180
7.500	....	....	....	....	....	....	.0304	.0191
7.750	....	....	....	....	....	....	.0319	.0201
8.000	....	....	....	....	....	....	.0332	.0215
8.250	....	....	....	....	....	....	.0344	.0227
8.500	....	....	....	....	....	....	....	.0240
8.750	....	....	....	....	....	....	....	.0253
9.000	....	....	....	....	....	....	....	.0267
9.250	....	....	....	....	....	....	....	.0280
9.500	....	....	....	....	....	....	....	.0292
9.750	....	....	....	....	....	....	....	.0304
10.000	....	....	....	....	....	....	....	.0316
10.250	....	....	....	....	....	....	....	.0327
10.500	....	....	....	....	....	....	....	.0335

Note: Calculate F_r to only nearest 4 significant figures

A. G. A. Report No. 2 TABLE XXXV

Y_1

Expansion Factors — Pipe Taps
Static Pressure Taken from Upstream Taps

Line Size	ORIFICE SIZES										
2″	1/8″ 1/4″	3/8″ 1/2″	5/8″	3/4″	7/8″	1″		1 1/8″			
3″	1/8″ 3/8″	1/2″ 3/4″	7/8″ 1″	1 1/8″ 1 1/4″	1 3/8″	1 1/2″		1 5/8″		1 3/4″	
4″	1/8″ 1/2″	5/8″ 1″	1 1/4″ 1 3/8″	1 1/2″ 1 5/8″	1 3/4″ 1 7/8″	2″	2 1/8″		2 1/4″	2 3/8″	
6″	1/8″ 7/8″	1″ 1 1/2″	1 5/8″ 2″	2 1/8″ 2 1/2″	2 5/8″ 2 7/8″	3″	3 1/8″	3 1/4″	3 3/8″	3 1/2″	3 5/8″
8″	1/8″ 1 1/8″	1 1/4″ 2″	2 1/8″ 2 3/4″	2 7/8″ 3 3/8″	3 1/2″ 3 3/4″	3 7/8″ 4″	4 1/4″		4 1/2″	4 3/4″	
10″	1/8″ 1 1/2″	1 5/8″ 2 1/2″	2 5/8″ 3 1/2″	3 5/8″ 4 1/4″	4 1/2″ 4 3/4″	5″	5 1/4″	5 1/2″	5 3/4″		6″
12″	1/8″ 1 3/4″	1 7/8″ 3″	3 1/8″ 4″	4 1/4″ 5″	5 1/4″ 5 1/2″	5 3/4″ 6″	6 1/4″	6 1/2″	6 3/4″	7″	7 1/4″
15 1/4″	1/8″ 2 1/4″	2 1/2″ 3 3/4″	3 7/8″ 5 1/4″	5 1/2″ 6 1/4″	6 1/2″ 7 1/4″	7 1/2″ 7 3/4″	8″	8 1/4″	8 1/2″	8 3/4″	9″

$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9990	.9989	.9988	.9985	.9984	.9982	.9981	.9980	.9979	.9978	.9977
0.2	.9981	.9979	.9976	.9971	.9968	.9964	.9962	.9961	.9959	.9957	.9954
0.3	.9971	.9968	.9964	.9956	.9952	.9946	.9944	.9941	.9938	.9935	.9931
0.4	.9962	.9958	.9951	.9942	.9936	.9928	.9925	.9921	.9917	.9913	.9908
0.5	.9952	.9947	.9939	.9927	.9919	.9910	.9906	.9902	.9897	.9891	.9885
0.6	.9943	.9937	.9927	.9913	.9903	.9892	.9887	.9882	.9876	.9870	.9862
0.7	.9933	.9926	.9915	.9898	.9887	.9874	.9869	.9862	.9856	.9848	.9840
0.8	.9923	.9916	.9903	.9883	.9871	.9857	.9850	.9843	.9835	.9826	.9817
0.9	.9914	.9905	.9891	.9869	.9855	.9839	.9831	.9823	.9814	.9805	.9794
1.0	.9904	.9895	.9878	.9854	.9839	.9821	.9812	.9803	.9794	.9783	.9771
1.1	.9895	.9884	.9866	.9840	.9823	.9803	.9794	.9784	.9773	.9761	.9748
1.2	.9885	.9874	.9854	.9825	.9807	.9785	.9775	.9764	.9752	.9739	.9725
1.3	.9876	.9863	.9842	.9811	.9791	.9767	.9756	.9744	.9732	.9718	.9702
1.4	.9866	.9853	.9830	.9796	.9775	.9749	.9737	.9725	.9711	.9696	.9679
1.5	.9857	.9842	.9818	.9782	.9758	.9731	.9719	.9705	.9690	.9674	.9656
1.6	9847	.9832	.9805	.9767	.9742	.9713	.9700	.9685	.9670	.9652	.9633
1.7	.9837	.9821	.9793	.9752	.9726	.9695	.9681	.9666	.9649	.9631	.9610
1.8	.9828	.9811	.9781	.9738	.9710	.9677	.9662	.9646	.9628	.9609	.9587
1.9	.9818	.9800	.9769	.9723	.9694	.9659	.9643	.9626	.9608	.9587	.9565
2.0	.9809	.9790	.9757	.9709	.9678	.9641	.9625	.9607	.9587	.9566	.9542
2.1	.9799	.9779	.9745	.9694	.9662	.9623	.9606	.9587	.9566	.9544	.9519
2.2	.9790	.9768	.9732	.9680	.9646	.9605	.9587	.9567	.9546	.9522	.9496
2.3	.9780	.9758	.9720	.9665	.9630	.9587	.9568	.9548	.9525	.9500	.9473
2.4	.9770	.9747	.9708	.9650	.9613	.9570	.9550	.9528	.9505	.9479	.9450
2.5	.9761	.9737	.9696	.9636	.9597	.9552	.9531	.9508	.9484	.9457	.9427
2.6	.9751	.9726	.9684	.9621	.9581	.9534	.9512	.9489	.9463	.9435	.9404
2.7	.9742	.9716	.9672	.9607	.9565	.9516	.9493	.9469	.9443	.9414	.9381
2.8	.9732	.9705	.9659	.9592	.9549	.9498	.9475	.9449	.9422	.9392	.9358
2.9	.9723	.9695	.9647	.9578	.9533	.9480	.9456	.9430	.9401	.9370	.9335
3.0	.9713	.9684	.9635	.9563	.9517	.9462	.9437	.9410	.9381	.9348	.9312
3.1	.9704	.9674	.9623	.9549	.9501	.9444	.9418	.9390	.9360	.9327	.9290
3.2	.9694	.9663	.9611	.9534	.9485	.9426	.9400	.9371	.9339	.9305	.9267
3.3	.9684	.9653	.9599	.9519	.9469	.9408	.9381	.9351	.9319	.9283	.9244
3.4	.9675	.9642	.9587	.9505	.9452	.9390	.9362	.9331	.9298	.9261	.9221
3.5	.9665	.9632	.9574	.9490	.9436	.9372	.9343	.9312	.9277	.9240	.9198
3.6	.9656	.9621	.9562	.9476	.9420	.9354	.9324	.9292	.9257	.9218	.9175
3.7	.9646	.9611	.9550	.9461	.9404	.9336	.9306	.9272	.9236	.9196	.9152
3.8	.9637	.9600	.9538	.9447	.9388	.9318	.9287	.9253	.9216	.9175	.9129
3.9	.9627	.9590	.9526	.9432	.9372	.9301	.9268	.9233	.9195	.9153	.9106
4.0	.9617	.9579	.9514	.9417	.9356	.9283	.9249	.9213	.9174	.9131	.9083

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30.

A. G. A. Report No. 2 TABLE XXXV — *Continued*

Y_1

Expansion Factors — Pipe Taps

Static Pressure Taken from Upstream Taps

Line Size	ORIFICE SIZES									
2"	1¼"					1⅜"				
3"	1⅞"				2"				2⅛"	
4"		2½"			2⅝"			2¾"		
6"		3¾"		3⅞"		4"				4¼"
8"		5"			5¼"			5½"		
10"		6¼"		6½"			6¾"		7"	
12"		7½"		7¾"		8"		8¼"		8½"
15¼"	9¼"	9½"		9¾"		10"	10¼"		10½"	10¾"
$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio									
	.61	.62	.63	.64	.65	.66	.67	.68	.69	.70
0.0	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
0.1	.9976	.9976	.9975	.9974	.9973	.9972	.9971	.9970	.9969	.9968
0.2	.9953	.9951	.9950	.9948	.9947	.9945	.9943	.9941	.9938	.9935
0.3	.9929	.9927	.9925	.9923	.9920	.9917	.9914	.9911	.9907	.9903
0.4	.9906	.9903	.9900	.9897	.9893	.9890	.9886	.9881	.9876	.9871
0.5	.9882	.9879	.9875	.9871	.9867	.9862	.9857	.9851	.9845	.9839
0.6	.9859	.9854	.9850	.9845	.9840	.9834	.9828	.9822	.9814	.9806
0.7	.9835	.9830	.9825	.9819	.9813	.9807	.9800	.9792	.9784	.9774
0.8	.9811	.9806	.9800	.9794	.9787	.9779	.9771	.9762	.9753	.9742
0.9	.9788	.9782	.9775	.9768	.9760	.9752	.9742	.9733	.9722	.9710
1.0	.9764	.9757	.9750	.9742	.9733	.9724	.9714	.9703	.9691	.9677
1.1	.9741	.9733	.9725	.9716	.9707	.9696	.9685	.9673	.9660	.9645
1.2	.9717	.9709	.9700	.9690	.9680	.9669	.9657	.9643	.9629	.9613
1.3	.9694	.9685	.9675	.9664	.9653	.9641	.9628	.9614	.9598	.9581
1.4	.9670	.9660	.9650	.9639	.9627	.9614	.9599	.9584	.9567	.9548
1.5	.9646	.9636	.9625	.9613	.9600	.9586	.9571	.9554	.9536	.9516
1.6	.9623	.9612	.9600	.9587	.9573	.9558	.9542	.9525	.9505	.9484
1.7	.9599	.9587	.9575	.9561	.9547	.9531	.9514	.9495	.9474	.9452
1.8	.9576	.9563	.9550	.9535	.9520	.9503	.9485	.9465	.9443	.9419
1.9	.9552	.9539	.9525	.9510	.9493	.9476	.9456	.9435	.9412	.9387
2.0	.9529	.9515	.9500	.9484	.9467	.9448	.9428	.9406	.9381	.9355
2.1	.9505	.9490	.9475	.9458	.9440	.9420	.9399	.9376	.9351	.9323
2.2	.9481	.9466	.9450	.9432	.9413	.9393	.9371	.9346	.9320	.9290
2.3	.9458	.9442	.9425	.9406	.9387	.9365	.9342	.9317	.9289	.9258
2.4	.9434	.9418	.9400	.9381	.9360	.9338	.9313	.9287	.9258	.9226
2.5	.9411	.9393	.9375	.9355	.9333	.9310	.9285	.9257	.9227	.9194
2.6	.9387	.9369	.9350	.9329	.9307	.9282	.9256	.9227	.9196	.9161
2.7	.9364	.9345	.9325	.9303	.9280	.9255	.9227	.9198	.9165	.9129
2.8	.9340	.9321	.9300	.9277	.9253	.9227	.9199	.9168	.9134	.9097
2.9	.9316	.9296	.9275	.9252	.9227	.9200	.9170	.9138	.9103	.9064
3.0	.9293	.9272	.9250	.9226	.9200	.9172	.9142	.9108	.9072	.9032
3.1	.9269	.9248	.9225	.9200	.9173	.9144	.9113	.9079	.9041	.9000
3.2	.9246	.9223	.9200	.9174	.9147	.9117	.9084	.9049	.9010	.8968
3.3	.9222	.9199	.9175	.9148	.9120	.9089	.9056	.9019	.8979	.8935
3.4	.9199	.9175	.9150	.9122	.9093	.9062	.9027	.8990	.8948	.8903
3.5	.9175	.9151	.9125	.9097	.9067	.9034	.8999	.8960	.8918	.8871
3.6	.9151	.9126	.9100	.9071	.9040	.9006	.8970	.8930	.8887	.8839
3.7	.9128	.9102	.9075	.9045	.9013	.8979	.8941	.8900	.8856	.8806
3.8	.9104	.9078	.9050	.9019	.8987	.8951	.8913	.8871	.8825	.8774
3.9	.9081	.9054	.9025	.8993	.8960	.8924	.8884	.8841	.8794	.8742
4.0	.9057	.9029	.9000	.8968	.8933	.8896	.8856	.8811	.8763	.8710

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30.

A. G. A. Report No. 2 TABLE XXXVI

Y_2

Expansion Factors — Pipe Taps
Static Pressure Taken from Downstream Taps

Line Size	ORIFICE SIZES										
2″	[illegible]	[illegible]	[illegible]	[illegible]	7/8″	1″		1 1/8″			
3″	1/8″ 3/8″	1/2″ 3/4″	7/8″ 1″	1 1/8″ 1 1/4″	1 3/8″	1 1/2″		1 5/8″		1 3/4″	
4″	1/8″ 1/2″	5/8″ 1″	1 1/8″ 1 3/8″	1 1/2″ 1 5/8″	1 3/4″ 1 7/8″	2″	2 1/8″		2 1/4″	2 3/8″	
6″	1/8″ 7/8″	1″ 1 1/2″	1 5/8″ 2″	2 1/8″ 2 1/2″	2 5/8″ 2 7/8″	3″	3 1/8″	3 1/4″	3 3/8″	3 1/2″	3 5/8″
8″	1/8″ 1 1/8″	1 1/4″ 2″	2 1/8″ 2 3/4″	2 7/8″ 3 3/8″	3 1/2″ 3 3/4″	3 7/8″ 4″	4 1/4″		4 1/2″	4 3/4″	
10″	1/8″ 1 1/2″	1 5/8″ 2 1/2″	2 5/8″ 3 1/2″	3 5/8″ 4 1/4″	4 1/2″ 4 3/4″	5″	5 1/4″	5 1/2″	5 3/4″		6″
12″	1/8″ 1 3/4″	1 7/8″ 3″	3 1/8″ 4″	4 1/4″ 5″	5 1/4″ 5 1/2″	5 3/4″ 6″	6 1/4″	6 1/2″	6 3/4″	7″	7 1/4″
15 1/4″	1/8″ 2 1/4″	2 1/2″ 3 3/4″	3 7/8″ 5 1/4″	5 1/2″ 6 1/4″	6 1/2″ 7 1/4″	7 1/2″ 7 3/4″	8″	8 1/4″	8 1/2″	8 3/4″	9″

$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio										
	.1	.2	.3	.4	.45	.50	.52	.54	.56	.58	.60
0.1	1.0008	1.0007	1.0006	1.0003	1.0002	1.0000	.9999	.9998	.9997	.9996	.9995
0.2	1.0017	1.0015	1.0012	1.0007	1.0004	1.0000	.9998	.9997	.9995	.9993	.9990
0.3	1.0025	1.0023	1.0018	1.0010	1.0006	1.0000	.9998	.9995	.9992	.9989	.9985
0.4	1.0033	1.0031	1.0024	1.0014	1.0008	1.0000	.9997	.9994	.9989	.9985	.9980
0.5	1.0042	1.0037	1.0029	1.0018	1.0010	1.0001	.9997	.9993	.9987	.9982	.9975
0.6	1.0051	1.0045	1.0035	1.0021	1.0012	1.0001	.9996	.9991	.9985	.9979	.9972
0.7	1.0059	1.0053	1.0042	1.0024	1.0014	1.0001	.9996	.9989	.9983	.9976	.9968
0.8	1.0068	1.0060	1.0048	1.0028	1.0016	1.0002	.9995	.9988	.9981	.9972	.9963
0.9	1.0076	1.0068	1.0053	1.0032	1.0018	1.0003	.9995	.9987	.9978	.9969	.9958
1.0	1.0084	1.0075	1.0059	1.0036	1.0021	1.0003	.9994	.9986	.9976	.9965	.9954
1.1	1.0093	1.0082	1.0065	1.0039	1.0023	1.0004	.9994	.9984	.9974	.9962	.9949
1.2	1.0101	1.0090	1.0071	1.0043	1.0025	1.0004	.9994	.9984	.9972	.9959	.9945
1.3	1.0110	1.0098	1.0077	1.0047	1.0027	1.0004	.9994	.9982	.9969	.9956	.9941
1.4	1.0119	1.0106	1.0083	1.0050	1.0030	1.0005	.9993	.9981	.9967	.9953	.9937
1.5	1.0127	1.0113	1.0089	1.0054	1.0032	1.0005	.9993	.9980	.9965	.9950	.9932
1.6	1.0136	1.0121	1.0095	1.0058	1.0034	1.0006	.9993	.9979	.9964	.9947	.9928
1.7	1.0143	1.0128	1.0101	1.0062	1.0035	1.0006	.9993	.9978	.9962	.9944	.9924
1.8	1.0152	1.0136	1.0107	1.0065	1.0038	1.0007	.9992	.9977	.9960	.9942	.9920
1.9	1.0161	1.0143	1.0113	1.0069	1.0041	1.0008	.9992	.9976	.9958	.9938	.9916
2.0	1.0169	1.0150	1.0119	1.0073	1.0044	1.0008	.9992	.9975	.9956	.9935	.9912
2.1	1.0177	1.0158	1.0125	1.0077	1.0046	1.0008	.9992	.9974	.9954	.9933	.9908
2.2	1.0185	1.0165	1.0131	1.0081	1.0048	1.0009	.9992	.9973	.9953	.9930	.9905
2.3	1.0194	1.0173	1.0137	1.0084	1.0050	1.0010	.9992	.9972	.9951	.9928	.9902
2.4	1.0202	1.0180	1.0142	1.0089	1.0053	1.0011	.9992	.9971	.9949	.9924	.9897
2.5	1.0210	1.0188	1.0148	1.0092	1.0056	1.0012	.9992	.9971	.9948	.9922	.9894
2.6	1.0219	1.0195	1.0154	1.0096	1.0058	1.0013	.9992	.9970	.9946	.9919	.9890
2.7	1.0230	1.0205	1.0162	1.0101	1.0061	1.0014	.9992	.9969	.9944	.9916	.9885
2.8	1.0236	1.0210	1.0166	1.0104	1.0063	1.0014	.9992	.9969	.9943	.9914	.9882
2.9	1.0244	1.0217	1.0173	1.0107	1.0065	1.0015	.9992	.9968	.9941	.9912	.9879
3.0	1.0251	1.0224	1.0179	1.0111	1.0067	1.0017	.9992	.9967	.9939	.9910	.9875
3.1	1.0259	1.0232	1.0185	1.0115	1.0070	1.0018	.9993	.9966	.9938	.9907	.9872
3.2	1.0267	1.0239	1.0190	1.0119	1.0072	1.0018	.9993	.9966	.9936	.9905	.9869
3.3	1.0276	1.0247	1.0196	1.0122	1.0075	1.0019	.9993	.9966	.9935	.9903	.9866
3.4	1.0284	1.0253	1.0202	1.0126	1.0077	1.0020	.9994	.9965	.9934	.9901	.9863
3.5	1.0291	1.0261	1.0208	1.0130	1.0080	1.0021	.9994	.9964	.9933	.9898	.9860
3.6	1.0301	1.0268	1.0214	1.0134	1.0083	1.0022	.9994	.9964	.9931	.9896	.9857
3.7	1.0309	1.0276	1.0219	1.0137	1.0085	1.0023	.9995	.9964	.9930	.9894	.9854
3.8	1.0316	1.0287	1.0225	1.0141	1.0088	1.0024	.9995	.9963	.9929	.9892	.9850
3.9	1.0324	1.0290	1.0231	1.0145	1.0091	1.0025	.9995	.9963	.9928	.9889	.9847
4.0	1.0332	1.0297	1.0237	1.0149	1.0093	1.0025	.9995	.9963	.9927	.9887	.9844

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30.
Use only nearest 4 significant figures.

Continued on page 105

A.G.A. Report No. 2 TABLE XXXVI — *Continued*

Y_2

Expansion Factors — Pipe Taps

Static Pressure Taken from Downstream Taps

Line Size	ORIFICE SIZES									
2″	1¼″					1⅜″				
3″	1⅞″				2″				2⅛″	
4″		2½″			2⅝″			2¾″		
6″		3¾″		3⅞″		4″				4¼″
8″		5″			5¼″			5½″		
10″		6¼″		6½″			6¾″		7″	
12″		7½″		7¾″		8″		8¼″		8½″
15¼″	9¼″	9½″		9¾″		10″	10¼″		10½″	10¾″

$\frac{h}{P}$ Ratio	$\beta = \frac{d}{D}$, Ratio .61	.62	.63	.64	.65	.66	.67	.68	.69	.70
0.1	.9994	.9994	.9993	.9992	.9991	.9990	.9989	.9988	.9987	.9986
0.2	.9989	.9987	.9986	.9984	.9983	.9981	.9979	.9977	.9974	.9971
0.3	.9983	.9981	.9979	.9977	.9974	.9971	.9968	.9965	.9962	.9958
0.4	.9978	.9975	.9972	.9969	.9966	.9963	.9959	.9954	.9949	.9944
0.5	.9973	.9970	.9966	.9962	.9958	.9953	.9948	.9942	.9936	.9930
0.6	.9969	.9964	.9959	.9954	.9949	.9943	.9937	.9931	.9924	.9916
0.7	.9963	.9958	.9953	.9947	.9940	.9932	.9928	.9920	.9912	.9903
0.8	.9957	.9952	.9947	.9941	.9933	.9925	.9918	.9909	.9900	.9889
0.9	.9952	.9947	.9940	.9933	.9925	.9917	.9907	.9898	.9888	.9876
1.0	.9947	.9941	.9934	.9926	.9917	.9908	.9898	.9887	.9876	.9863
1.1	.9942	.9935	.9927	.9919	.9910	.9899	.9889	.9877	.9865	.9849
1.2	.9938	.9929	.9921	.9911	.9902	.9890	.9878	.9865	.9851	.9835
1.3	.9933	.9924	.9914	.9904	.9893	.9881	.9869	.9855	.9839	.9823
1.4	.9928	.9918	.9908	.9897	.9886	.9873	.9859	.9845	.9827	.9810
1.5	.9923	.9913	.9903	.9891	.9878	.9865	.9849	.9834	.9815	.9796
1.6	.9919	.9908	.9897	.9883	.9870	.9856	.9840	.9823	.9804	.9784
1.7	.9914	.9902	.9890	.9876	.9863	.9848	.9831	.9813	.9793	.9771
1.8	.9909	.9897	.9884	.9870	.9855	.9840	.9842	.9802	.9781	.9758
1.9	.9905	.9892	.9878	.9863	.9848	.9831	.9812	.9792	.9770	.9746
2.0	.9900	.9887	.9872	.9857	.9840	.9823	.9803	.9782	.9759	.9733
2.1	.9895	.9882	.9867	.9851	.9833	.9815	.9794	.9771	.9748	.9720
2.2	.9891	.9876	.9861	.9844	.9826	.9807	.9785	.9762	.9737	.9708
2.3	.9887	.9871	.9855	.9837	.9818	.9798	.9776	.9752	.9726	.9696
2.4	.9882	.9866	.9850	.9831	.9812	.9791	.9768	.9742	.9715	.9683
2.5	.9878	.9861	.9844	.9825	.9805	.9783	.9759	.9732	.9704	.9672
2.6	.9874	.9857	.9839	.9819	.9798	.9775	.9750	.9722	.9693	.9660
2.7	.9869	.9850	.9832	.9811	.9788	.9765	.9738	.9709	.9679	.9644
2.8	.9866	.9847	.9828	.9807	.9784	.9759	.9732	.9703	.9672	.9636
2.9	.9861	.9842	.9822	.9800	.9777	.9751	.9723	.9693	.9660	.9624
3.0	.9857	.9838	.9817	.9794	.9770	.9744	.9715	.9685	.9650	.9613
3.1	.9853	.9834	.9812	.9788	.9763	.9737	.9707	.9676	.9640	.9602
3.2	.9849	.9829	.9807	.9783	.9757	.9729	.9699	.9666	.9630	.9590
3.3	.9846	.9825	.9802	.9777	.9750	.9722	.9690	.9657	.9619	.9579
3.4	.9842	.9820	.9797	.9771	.9744	.9715	.9683	.9648	.9609	.9568
3.5	.9838	.9816	.9792	.9765	.9738	.9707	.9675	.9639	.9600	.9556
3.6	.9834	.9811	.9787	.9760	.9731	.9700	.9666	.9630	.9590	.9545
3.7	.9831	.9807	.9782	.9755	.9725	.9693	.9658	.9621	.9579	.9534
3.8	.9827	.9802	.9777	.9749	.9719	.9686	.9651	.9613	.9570	.9523
3.9	.9823	.9798	.9773	.9743	.9712	.9679	.9643	.9604	.9560	.9512
4.0	.9820	.9795	.9767	.9738	.9706	.9673	.9636	.9595	.9551	.9502

NOTE: Above tables are for use on natural gas and are based on ratio of specific-heats equal to 1.30.
Use only nearest 4 significant figures.

TABLE XXXVII

F_{PV}

For Base Temp. Gravity .560–.700

These factors are applicable for temperatures of 60° to 64° F., inclusive

Press. Lbs./ Sq. In. Gauge	Specific Gravity .560	.570	.580	.590	.600	.610	.620	.630	.640	.650	.660	.670	.680	.690	.700
10	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.002	1 002	1.002
20	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.003	1.003	1.003	1.003	1.003
30	1.002	1.002	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.004	1.004	1.004	1.004	1.004
40	1.003	1.003	1.003	1.003	1.004	1.004	1.004	1.004	1.004	1.004	1.005	1.005	1.005	1.005	1.005
50	1.004	1.004	1.004	1.004	1.005	1.005	1.005	1.005	1.005	1.006	1.006	1.006	1.006	1.007	1.007
60	1.005	1.005	1.005	1.005	1.005	1.006	1.006	1.005	1.006	1.007	1.007	1.007	1.007	1.008	1.008
70	1.005	1.006	1.005	1.006	1.005	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.008	1.009	1.009
80	1.006	1.006	1.005	1.006	1.007	1.007	1.007	1.008	1.008	1.008	1.009	1.009	1.009	1.010	1.010
90	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.009	1.009	1.009	1.010	1.010	1.011	1.011	1.011
100	1.007	1.008	1.008	1.008	1.009	1.009	1.009	1.010	1.010	1.010	1.011	1.011	1.012	1.012	1.012
110	1.008	1.008	1.009	1.009	1.010	1.010	1.010	1.011	1.011	1.011	1.012	1.012	1.013	1.013	1.014
120	1.009	1.009	1.010	1.010	1.019	1.011	1.011	1.012	1.012	1.012	1.013	1.013	1.014	1.015	1.015
130	1.009	1.010	1.010	1.011	1.011	1.012	1.012	1.013	1.013	1.013	1.014	1.014	1.015	1.016	1.016
140	1.010	1.011	1.011	1.012	1.012	1.013	1.013	1.014	1.014	1.014	1.015	1.015	1.016	1.017	1.017
150	1.011	1.011	1.012	1.012	1.013	1.013	1.014	1.014	1.015	1.015	1.016	1.016	1.017	1.018	1.019
160	1.012	1.012	1.013	1.013	1.014	1.014	1.015	1.015	1.016	1.016	1.017	1.018	1.018	1.019	1.020
170	1.012	1.013	1.013	1.014	1.014	1.015	1.015	1.015	1.017	1.017	1.018	1.019	1.020	1.020	1.021
180	1.013	1.013	1.014	1.015	1.015	1.016	1.016	1.017	1.018	1.019	1.019	1.020	1.021	1.021	1.022
190	1.014	1.014	1.015	1.015	1.016	1.016	1.017	1.018	1.019	1.020	1.020	1.021	1.022	1.023	1.023
200	1.014	1.015	1.016	1.016	1.017	1.017	1.018	1.019	1.020	1.021	1.022	1.022	1.023	1.024	1.025
210	1.015	1.015	1.016	1.017	1.018	1.018	1.019	1.020	1.021	1.022	1.023	1.023	1.024	1.025	1.026
220	1.016	1.016	1.017	1.017	1.018	1.019	1.020	1.021	1.022	1.023	1.024	1.024	1.025	1.026	1.027
230	1.016	1.017	1.018	1.018	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.026	1.027	1.028
240	1.017	1.018	1.019	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.027	1.028	1.029	1.030
250	1.018	1.018	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.027	1.028	1.029	1.030	1.031
260	1.018	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.027	1.028	1.029	1.030	1.031	1.032
270	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.027	1.028	1.029	1.030	1.031	1.032	1.033
280	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.027	1.028	1.029	1.030	1.031	1.032	1.033	1.034
290	1.020	1.021	1.022	1.023	1.024	1.025	1.026	1.028	1.029	1.030	1.031	1.032	1.034	1.035	1.036
300	1.021	1.022	1.023	1.024	1.025	1.026	1.027	1.029	1.030	1.031	1.032	1.034	1.035	1.036	1.037
310	1.021	1.022	1.023	1.024	1.025	1.027	1.028	1.030	1.031	1.032	1.034	1.035	1.036	1.037	1.039
320	1.022	1.023	1.024	1.025	1.026	1.028	1.029	1.031	1.032	1.033	1.035	1.036	1.037	1.039	1.040
330	1.023	1.024	1.025	1.026	1.027	1.029	1.030	1.032	1.033	1.035	1.036	1.037	1.039	1.040	1.042
340	1.023	1.024	1.026	1.027	1.028	1.030	1.031	1.033	1.034	1.036	1.037	1.038	1.040	1.042	1.043
350	1.024	1.025	1.026	1.028	1.029	1.031	1.032	1.034	1.035	1.037	1.038	1.040	1.042	1.043	1.044
360	1.025	1.026	1.027	1.028	1.030	1.032	1.033	1.035	1.036	1.038	1.039	1.041	1.043	1.044	1.046
370	1.025	1.027	1.028	1.029	1.031	1.032	1.034	1.036	1.037	1.039	1.040	1.042	1.044	1.045	1.047
380	1.026	1.027	1.029	1.030	1.032	1.033	1.035	1.036	1.038	1.040	1.041	1.043	1.045	1.046	1.048
390	1.027	1.028	1.029	1.031	1.032	1.034	1.036	1.037	1.039	1.041	1.042	1.044	1.046	1.048	1.050
400	1.027	1.029	1.030	1.032	1.033	1.035	1.037	1.038	1.040	1.042	1.044	1.046	1.048	1.049	1.051
410	1.028	1.030	1.031	1.032	1.034	1.036	1.038	1.039	1.041	1.043	1.045	1.047	1.049	1.051	1.052
420	1.029	1.030	1.032	1.033	1.035	1.037	1.039	1.040	1.042	1.044	1.046	1.048	1.050	1.052	1.054
430	1.029	1.031	1.032	1.034	1.036	1.038	1.040	1.041	1.043	1.046	1.048	1.050	1.052	1.054	1.055
440	1.030	1.032	1.033	1.035	1.037	1.039	1.041	1.042	1.044	1.047	1.049	1.051	1.053	1.055	1.057
450	1.031	1.032	1.034	1.036	1.038	1.040	1.042	1.044	1.046	1.048	1.050	1.052	1.054	1.056	1.058
460	1.031	1.033	1.035	1.037	1.039	1.041	1.043	1.045	1.047	1.049	1.051	1.053	1.056	1.058	1.060
470	1.032	1.034	1.036	1.038	1.040	1.042	1.044	1.046	1.048	1.050	1.052	1.054	1.057	1.059	1.061
480	1.033	1.035	1.037	1.039	1.041	1.043	1.045	1.047	1.049	1.051	1.053	1.055	1.058	1.060	1.062
490	1.034	1.036	1.038	1.040	1.042	1.044	1.046	1.048	1.050	1.052	1.054	1.056	1.059	1.062	1.064
500	1.035	1.037	1.039	1.041	1.043	1.045	1.047	1.049	1.051	1.053	1.055	1.057	1.060	1.063	1.066

Note: Each heading is inclusive to next higher heading. Do not interpolate.
For effective temperature range and example, see page 198.
From: California Natural Gasoline Association Bulletin TS-402.

TABLE XXXVII — *Continued*

F_{PV}

For Base Temp. Gravity .710–.850

These factors are applicable for temperatures of 60° to 64° F., inclusive

Press. Lbs./Sq. In. Gauge	Specific Gravity .710	.720	.730	.740	.750	.760	.770	.780	.790	.800	.810	.820	.830	.840	.850
10	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.003	1.003
20	1.003	1.003	1.003	1.003	1.003	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.005
30	1.004	1.004	1.004	1.004	1.004	1.005	1.005	1.005	1.005	1.006	1.006	1.006	1.006	1.006	1.005
40	1.005	1.006	1.005	1.006	1.006	1.006	1.006	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.008
50	1.007	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.008	1.009	1.009	1.009	1.010	1.010	1.010
60	1.008	1.009	1.009	1.009	1.009	1.009	1.009	1.010	1.010	1.011	1.011	1.011	1.012	1.012	1.012
70	1.009	1.010	1.010	1.010	1.010	1.011	1.011	1.011	1.011	1.012	1.012	1.013	1.013	1.013	1.014
80	1.010	1.011	1.011	1.011	1.012	1.012	1.012	1.013	1.013	1.014	1.014	1.014	1.015	1.015	1.016
90	1.011	1.012	1.012	1.012	1.013	1.013	1.014	1.014	1.014	1.015	1.015	1.016	1.016	1.016	1.017
100	1.013	1.013	1.013	1.014	1.015	1.015	1.015	1.016	1.016	1.017	1.017	1.018	1.018	1.019	1.019
110	1.014	1.015	1.015	1.015	1.016	1.017	1.017	1.017	1.018	1.018	1.019	1.020	1.020	1.021	1.021
120	1.015	1.016	1.016	1.017	1.018	1.018	1.018	1.019	1.019	1.020	1.020	1.021	1.021	1.022	1.022
130	1.016	1.017	1.017	1.018	1.019	1.020	1.020	1.021	1.021	1.022	1.022	1.023	1.023	1.024	1.024
140	1.017	1.018	1.018	1.019	1.020	1.021	1.022	1.022	1.023	1.023	1.024	1.024	1.025	1.026	1.026
150	1.019	1.020	1.020	1.021	1.022	1.023	1.023	1.024	1.024	1.025	1.025	1.026	1.027	1.028	1.028
160	1.020	1.021	1.021	1.022	1.023	1.024	1.025	1.025	1.026	1.026	1.027	1.028	1.029	1.030	1.030
170	1.022	1.022	1.022	1.024	1.025	1.026	1.026	1.027	1.027	1.028	1.029	1.030	1.031	1.032	1.032
180	1.023	1.024	1.024	1.025	1.026	1.027	1.028	1.029	1.029	1.030	1.031	1.032	1.033	1.034	1.035
190	1.024	1.025	1.025	1.026	1.027	1.028	1.029	1.030	1.031	1.031	1.032	1.033	1.035	1.035	1.037
200	1.026	1.026	1.027	1.028	1.029	1.030	1.031	1.032	1.033	1.033	1.034	1.035	1.037	1.038	1.039
210	1.027	1.028	1.028	1.029	1.031	1.032	1.032	1.033	1.034	1.035	1.035	1.037	1.038	1.039	1.040
220	1.028	1.029	1.030	1.031	1.032	1.033	1.034	1.035	1.036	1.037	1.038	1.039	1.040	1.041	1.042
230	1.029	1.030	1.031	1.032	1.034	1.035	1.036	1.037	1.038	1.038	1.039	1.041	1.042	1.043	1.044
240	1.031	1.032	1.032	1.033	1.035	1.036	1.037	1.038	1.039	1.040	1.041	1.043	1.044	1.045	1.046
250	1.032	1.033	1.034	1.035	1.037	1.038	1.039	1.040	1.041	1.042	1.043	1.045	1.046	1.048	1.049
260	1.033	1.034	1.036	1.036	1.038	1.039	1.040	1.042	1.043	1.044	1.045	1.047	1.049	1.050	1.051
270	1.035	1.036	1.037	1.038	1.040	1.041	1.042	1.043	1.045	1.046	1.047	1.049	1.051	1.053	1.054
280	1.036	1.037	1.038	1.039	1.041	1.042	1.044	1.045	1.047	1.048	1.050	1.051	1.053	1.055	1.056
290	1.037	1.039	1.040	1.041	1.043	1.044	1.045	1.046	1.048	1.050	1.052	1.053	1.055	1.058	1.059
300	1.039	1.040	1.041	1.043	1.044	1.046	1.047	1.048	1.050	1.052	1.054	1.055	1.057	1.060	1.062
310	1.040	1.041	1.043	1.044	1.046	1.047	1.049	1.050	1.052	1.053	1.055	1.057	1.060	1.063	1.064
320	1.042	1.043	1.044	1.046	1.048	1.049	1.051	1.052	1.054	1.055	1.057	1.059	1.062	1.064	1.066
330	1.043	1.044	1.046	1.048	1.049	1.050	1.052	1.054	1.056	1.057	1.059	1.061	1.064	1.067	1.069
340	1.044	1.046	1.048	1.049	1.051	1.052	1.054	1.056	1.058	1.059	1.061	1.063	1.066	1.069	1.071
350	1.046	1.047	1.049	1.051	1.053	1.054	1.056	1.058	1.060	1.062	1.064	1.065	1.068	1.072	1.074
360	1.047	1.049	1.051	1.052	1.054	1.056	1.058	1.060	1.062	1.064	1.066	1.068	1.071	1.074	1.076
370	1.049	1.050	1.052	1.054	1.056	1.058	1.060	1.062	1.064	1.066	1.068	1.070	1.073	1.076	1.078
380	1.050	1.052	1.054	1.056	1.057	1.059	1.061	1.064	1.066	1.068	1.070	1.073	1.075	1.078	1.081
390	1.052	1.054	1.056	1.057	1.059	1.060	1.063	1.065	1.067	1.070	1.072	1.075	1.077	1.080	1.083
400	1.053	1.056	1.058	1.059	1.060	1.062	1.065	1.067	1.069	1.072	1.074	1.077	1.079	1.082	1.085
410	1.055	1.057	1.060	1.061	1.062	1.064	1.066	1.069	1.071	1.074	1.076	1.079	1.082	1.085	1.088
420	1.056	1.059	1.062	1.063	1.064	1.066	1.068	1.071	1.073	1.075	1.078	1.081	1.084	1.087	1.090
430	1.058	1.061	1.064	1.065	1.066	1.068	1.070	1.073	1.075	1.077	1.080	1.083	1.086	1.089	1.092
440	1.059	1.062	1.065	1.067	1.068	1.070	1.072	1.074	1.077	1.079	1.082	1.085	1.088	1.091	1.095
450	1.060	1.063	1.067	1.069	1.070	1.072	1.074	1.075	1.079	1.081	1.084	1.088	1.090	1.093	1.097
460	1.062	1.064	1.068	1.070	1.071	1.073	1.076	1.078	1.081	1.083	1.086	1.090	1.092	1.095	1.099
470	1.064	1.065	1.069	1.071	1.073	1.075	1.078	1.080	1.083	1.085	1.088	1.092	1.095	1.098	1.102
480	1.065	1.067	1.070	1.072	1.075	1.077	1.080	1.082	1.085	1.087	1.090	1.094	1.097	1.100	1.104
490	1.066	1.068	1.071	1.073	1.076	1.078	1.081	1.084	1.086	1.089	1.092	1.096	1.099	1.102	1.106
500	1.068	1.070	1.073	1.075	1.078	1.080	1.083	1.085	1.088	1.091	1.094	1.098	1.101	1.104	1.108

Note: Each heading is inclusive to next higher heading. Do not interpolate.
For effective temperature range and example, see page 198.
From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 198

TABLE XXXVII — *Continued*

F_{PV}

For Base Temp. Gravity .860–1.000

These factors are applicable for temperatures of 60° to 64° F., inclusive

Press. Lbs./ Sq. In. Gauge	Specific Gravity .860	.870	.880	.890	.900	.910	.920	.930	.940	.950	.960	.970	.980	.990	1.000
0	1.000	1.000	1.000	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
5	1.001	1.001	1.001	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
10	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003
15	1.003	1.003	1.003	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.004	1.005	1.005
20	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.005	1.006	1.006	1.006	1.006	1.006
25	1.005	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.006	1.007	1.007	1.007	1.007	1.007	1.007
30	1.006	1.007	1.007	1.007	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.008	1.008	1.008	1.009
35	1.007	1.008	1.008	1.008	1.008	1.008	1.008	1.009	1.009	1.009	1.009	1.009	1.010	1.010	1.010
40	1.008	1.009	1.009	1.009	1.009	1.009	1.009	1.010	1.010	1.010	1.011	1.011	1.011	1.011	1.012
45	1.009	1.010	1.010	1.010	1.010	1.010	1.010	1.011	1.011	1.012	1.012	1.012	1.012	1.013	1.013
50	1.010	1.011	1.011	1.011	1.011	1.011	1.012	1.012	1.012	1.013	1.013	1.013	1.014	1.014	1.014
55	1.011	1.012	1.012	1.012	1.012	1.012	1.013	1.013	1.014	1.014	1.014	1.015	1.015	1.015	1.016
60	1.012	1.013	1.013	1.013	1.013	1.013	1.014	1.014	1.015	1.015	1.016	1.016	1.016	1.016	1.017
65	1.013	1.014	1.014	1.014	1.014	1.015	1.015	1.015	1.016	1.016	1.017	1.017	1.017	1.018	1.018
70	1.014	1.015	1.015	1.015	1.015	1.016	1.016	1.017	1.017	1.017	1.018	1.018	1.019	1.019	1.020
75	1.015	1.016	1.016	1.016	1.016	1.017	1.017	1.018	1.018	1.019	1.019	1.020	1.020	1.020	1.021
80	1.016	1.017	1.017	1.017	1.017	1.018	1.018	1.019	1.019	1.020	1.020	1.021	1.021	1.022	1.022
85	1.017	1.018	1.018	1.018	1.019	1.019	1.020	1.020	1.021	1.021	1.022	1.022	1.023	1.023	1.024
90	1.018	1.019	1.019	1.019	1.020	1.020	1.021	1.021	1.022	1.022	1.023	1.023	1.024	1.025	1.025
95	1.019	1.020	1.020	1.020	1.021	1.021	1.022	1.023	1.023	1.024	1.024	1.025	1.025	1.026	1.027
100	1.020	1.021	1.021	1.021	1.022	1.022	1.023	1.024	1.024	1.025	1.026	1.026	1.027	1.027	1.028
105	1.021	1.022	1.022	1.022	1.023	1.023	1.024	1.025	1.026	1.026	1.027	1.027	1.028	1.029	1.029
110	1.022	1.023	1.023	1.023	1.024	1.025	1.025	1.026	1.027	1.027	1.028	1.029	1.030	1.030	1.031
115	1.023	1.024	1.024	1.024	1.025	1.026	1.027	1.027	1.028	1.029	1.029	1.030	1.031	1.032	1.032
120	1.024	1.025	1.025	1.026	1.026	1.027	1.028	1.029	1.029	1.030	1.031	1.032	1.032	1.033	1.034
125	1.025	1.026	1.026	1.027	1.027	1.028	1.029	1.030	1.031	1.031	1.032	1.033	1.034	1.034	1.035
130	1.026	1.027	1.027	1.028	1.028	1.029	1.030	1.031	1.032	1.033	1.033	1.034	1.035	1.036	1.037
135	1.026	1.028	1.028	1.029	1.029	1.030	1.031	1.032	1.033	1.034	1.035	1.036	1.037	1.037	1.038
140	1.027	1.029	1.029	1.030	1.031	1.031	1.033	1.034	1.034	1.035	1.036	1.037	1.038	1.039	1.040
145	1.028	1.030	1.030	1.031	1.032	1.032	1.034	1.035	1.036	1.036	1.037	1.038	1.039	1.040	1.041
150	1.030	1.031	1.031	1.032	1.033	1.034	1.035	1.036	1.037	1.038	1.038	1.040	1.041	1.041	1.042
155	1.031	1.032	1.032	1.033	1.034	1.035	1.036	1.037	1.038	1.039	1.040	1.041	1.042	1.043	1.044
160	1.032	1.033	1.033	1.034	1.035	1.036	1.038	1.039	1.039	1.040	1.041	1.042	1.043	1.044	1.045
165	1.033	1.034	1.034	1.035	1.036	1.037	1.039	1.040	1.041	1.041	1.042	1.044	1.045	1.046	1.047
170	1.034	1.035	1.035	1.036	1.037	1.038	1.040	1.041	1.042	1.043	1.044	1.045	1.046	1.047	1.048
175	1.035	1.036	1.036	1.037	1.038	1.039	1.041	1.042	1.043	1.044	1.045	1.046	1.048	1.049	1.050
180	1.036	1.037	1.037	1.038	1.039	1.040	1.042	1.043	1.044	1.045	1.046	1.048	1.049	1.050	1.051
185	1.037	1.038	1.038	1.040	1.041	1.042	1.043	1.045	1.045	1.047	1.048	1.049	1.051	1.052	1.053
190	1.038	1.039	1.040	1.041	1.042	1.043	1.045	1.046	1.046	1.048	1.049	1.050	1.052	1.053	1.054
195	1.039	1.040	1.041	1.042	1.043	1.044	1.045	1.047	1.047	1.049	1.050	1.052	1.053	1.054	1.056
200	1.040	1.041	1.042	1.043	1.044	1.045	1.047	1.048	1.048	1.050	1.052	1.053	1.055	1.056	1.057

Note: Each heading is inclusive to next higher heading. Do not interpolate.

Example: For any gauge pressure of 180 to 184 lbs.. inclusive, use 180.

For any specific gravity of .900 to .909, inclusive, use .900.

With these conditions F_{PV} for base temperature is 1.039 and applies to all temperatures of 60° to 64°F., inclusive, without further reference.

For temperatures other than 60° to 64° F., inclusive, select this factor from Table XXXVIII, pages 201 and 202. and obtain adjusted factor under desired temperature.

From: California Natural Gasoline Association Bulletin TS-402.

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TABLE XXXVII — *Continued*

F_{PV}

For Base Temp. Gravity 1.02–1.26

These factors are applicable for temperatures of 60° to 64° F., inclusive

Press. Lbs./ Sq. In. Gauge	Specific Gravity												
	1.02	1.04	1.06	1.08	1.10	1.12	1.14	1.16	1.18	1.20	1.22	1.24	1.26
0	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001
5	1.002	1.002	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.004
10	1.003	1.003	1.004	1.004	1.005	1.005	1.005	1.005	1.005	1.005	1.006	1.006	1.006
15	1.005	1.005	1.006	1.006	1.006	1.006	1.007	1.007	1.007	1.008	1.008	1.008	1.009
20	1.007	1.007	1.008	1.008	1.008	1.008	1.008	1.009	1.009	1.010	1.010	1.011	1.011
25	1.008	1.008	1.009	1.009	1.010	1.010	1.010	1.011	1.011	1.012	1.012	1.013	1.014
30	1.010	1.010	1.011	1.011	1.011	1.012	1.012	1.013	1.013	1.014	1.015	1.015	1.016
35	1.011	1.011	1.013	1.013	1.013	1.014	1.014	1.015	1.016	1.016	1.017	1.018	1.018
40	1.013	1.013	1.014	1.015	1.015	1.015	1.016	1.017	1.018	1.018	1.019	1.020	1.021
45	1.014	1.014	1.016	1.016	1.017	1.017	1.018	1.019	1.020	1.020	1.021	1.022	1.023
50	1.016	1.016	1.017	1.018	1.019	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026
55	1.017	1.018	1.019	1.020	1.020	1.021	1.022	1.022	1.024	1.025	1.026	1.027	1.028
60	1.018	1.019	1.021	1.021	1.022	1.023	1.024	1.024	1.026	1.027	1.028	1.029	1.031
65	1.020	1.021	1.022	1.023	1.024	1.024	1.025	1.026	1.028	1.029	1.030	1.032	1.033
70	1.021	1.022	1.024	1.025	1.025	1.026	1.027	1.028	1.030	1.031	1.032	1.034	1.036
75	1.023	1.024	1.026	1.026	1.027	1.028	1.029	1.030	1.032	1.033	1.034	1.036	1.038
80	1.024	1.025	1.027	1.028	1.029	1.030	1.031	1.032	1.034	1.035	1.037	1.039	1.040
85	1.026	1.027	1.029	1.030	1.031	1.032	1.033	1.034	1.036	1.038	1.039	1.041	1.043
90	1.027	1.028	1.031	1.032	1.033	1.034	1.035	1.036	1.038	1.040	1.042	1.044	1.046
95	1.029	1.030	1.033	1.033	1.035	1.036	1.037	1.039	1.041	1.043	1.044	1.046	1.048
100	1.031	1.032	1.034	1.035	1.037	1.038	1.039	1.041	1.043	1.045	1.047	1.049	1.051
105	1.032	1.034	1.036	1.037	1.039	1.040	1.042	1.043	1.046	1.048	1.050	1.052	1.054
110	1.034	1.036	1.038	1.039	1.041	1.042	1.044	1.046	1.048	1.050	1.052	1.054	1.057
115	1.035	1.037	1.039	1.041	1.043	1.044	1.046	1.048	1.050	1.053	1.055	1.057	1.059
120	1.037	1.039	1.041	1.043	1.045	1.047	1.048	1.050	1.053	1.055	1.057	1.060	1.062
125	1.039	1.041	1.043	1.045	1.047	1.049	1.050	1.052	1.055	1.058	1.060	1.062	1.065
130	1.040	1.042	1.045	1.047	1.049	1.051	1.053	1.055	1.057	1.060	1.063	1.065	1.068
135	1.042	1.044	1.047	1.049	1.051	1.053	1.055	1.057	1.060	1.063	1.065	1.068	1.071
140	1.044	1.046	1.048	1.051	1.053	1.055	1.057	1.059	1.062	1.065	1.068	1.070	1.073
145	1.045	1.048	1.050	1.053	1.055	1.057	1.059	1.062	1.064	1.068	1.070	1.073	1.076
150	1.047	1.049	1.052	1.054	1.057	1.059	1.061	1.064	1.067	1.070	1.073	1.076	1.079
155	1.049	1.051	1.054	1.056	1.059	1.061	1.063	1.066	1.069	1.072	1.076	1.078	1.082
160	1.050	1.053	1.056	1.058	1.061	1.063	1.066	1.069	1.071	1.075	1.078	1.081	1.084
165	1.052	1.054	1.057	1.060	1.063	1.065	1.068	1.071	1.074	1.077	1.081	1.083	1.087
170	1.053	1.056	1.059	1.062	1.065	1.067	1.070	1.073	1.076	1.080	1.083	1.086	1.090
175	1.055	1.058	1.061	1.064	1.067	1.070	1.072	1.076	1.078	1.082	1.086	1.089	1.092
180	1.057	1.059	1.063	1.066	1.069	1.072	1.074	1.078	1.081	1.085	1.089	1.092	1.095
185	1.058	1.061	1.064	1.068	1.071	1.074	1.076	1.080	1.083	1.087	1.091	1.094	1.098
190	1.060	1.063	1.066	1.070	1.073	1.076	1.079	1.082	1.085	1.090	1.094	1.097	1.101
195	1.062	1.065	1.068	1.072	1.075	1.078	1.081	1.085	1.088	1.092	1.096	1.099	1.104
200	1.064	1.067	1.070	1.073	1.077	1.080	1.083	1.087	1.090	1.094	1.099	....	....

Note: Each heading is inclusive to next higher heading. Do not interpolate.
For example, see page 198.
From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 200

TABLE XXXVII — *Continued*

F_{PV}

For Base Temp. Gravity 1.28–1.50

These factors are applicable for temperatures of 60° to 64° F., inclusive

Press. Lbs./ Sq. In. Gauge	Specific Gravity											
	1.28	1.30	1.32	1.34	1.36	1.38	1.40	1.42	1.44	1.46	1.48	1.50
0	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002
5	1.004	1.004	1.004	1.005	1.005	1.005	1.005	1.005	1.006	1.006	1.006	1.006
10	1.007	1.007	1.007	1.007	1.008	1.008	1.008	1.009	1.009	1.009	1.010	1.010
15	1.009	1.009	1.010	1.010	1.010	1.011	1.012	1.012	1.013	1.013	1.014	1.014
20	1.012	1.012	1.012	1.013	1.013	1.014	1.015	1.016	1.016	1.017	1.017	1.018
25	1.014	1.015	1.015	1.016	1.016	1.017	1.018	1.019	1.020	1.020	1.021	1.022
30	1.017	1.017	1.017	1.018	1.019	1.020	1.021	1.022	1.023	1.024	1.025	1.026
35	1.019	1.020	1.020	1.021	1.022	1.023	1.024	1.026	1.027	1.028	1.029	1.030
40	1.022	1.023	1.023	1.024	1.025	1.026	1.028	1.029	1.030	1.031	1.032	1.034
45	1.024	1.025	1.026	1.027	1.028	1.029	1.031	1.032	1.034	1.035	1.036	1.037
50	1.027	1.028	1.028	1.030	1.031	1.032	1.034	1.036	1.037	1.038	1.040	1.041
55	1.029	1.030	1.031	1.033	1.034	1.035	1.037	1.039	1.041	1.042	1.044	1.045
60	1.032	1.033	1.034	1.035	1.037	1.039	1.040	1.042	1.044	1.046	1.047	1.049
65	1.034	1.036	1.037	1.038	1.040	1.042	1.044	1.046	1.048	1.049	1.051	1.053
70	1.037	1.039	1.039	1.041	1.043	1.045	1.047	1.049	1.051	1.053	1.055	1.057
75	1.040	1.041	1.042	1.044	1.045	1.048	1.050	1.052	1.055	1.057	1.059	1.061
80	1.042	1.044	1.045	1.047	1.048	1.051	1.053	1.056	1.058	1.060	1.062	1.065
85	1.044	1.047	1.047	1.049	1.051	1.054	1.056	1.059	1.062	1.064	1.066	1.069
90	1.047	1.050	1.050	1.052	1.054	1.057	1.060	1.062	1.065	1.068	1.070	1.073
95	1.050	1.053	1.053	1.055	1.057	1.060	1.063	1.066	1.069	1.071	1.074	1.076
100	1.053	1.056	1.056	1.058	1.060	1.063	1.066	1.069	1.072	1.075	1.078	1.080
105	1.056	1.059	....	....	....	....	....	....	....	....	....	....
110	1.059	1.062	....	....	....	....	....	....	....	....	....	....
115	1.062	1.065	....	....	....	....	....	....	....	....	....	....
120	1.065	1.068	....	....	....	....	....	....	....	....	....	....
125	1.068	1.071	....	....	....	....	....	....	....	....	....	....
130	1.071	1.074	....	....	....	....	....	....	....	....	....	....
135	1.073	1.077	....	....	....	....	....	....	....	....	....	....
140	1.076	1.080	....	....	....	....	....	....	....	....	....	....
145	1.079	1.083	....	....	....	....	....	....	....	....	....	....
150	1.082	1.086	....	....	....	....	....	....	....	....	....	....
155	1.085	1.089	....	....	....	....	....	....	....	....	....	....
160	1.088	1.092	....	....	....	....	....	....	....	....	....	....
165	1.091	1.095	....	....	....	....	....	....	....	....	....	....
170	1.093	1.098	....	....	....	....	....	....	....	....	....	....
175	1.096	1.101	....	....	....	....	....	....	....	....	....	....
180	1.099	1.104	....	....	....	....	....	....	....	....	....	....
185	1.102	1.107	....	....	....	....	....	....	....	....	....	....
190	1.105	1.110	....	....	....	....	....	....	....	....	....	....
195	1.108	1.113	....	....	....	....	....	....	....	....	....	....
200	....	....	....	....	....	....	....	....	....	....	....	....

Note: Each heading is inclusive to next higher heading. Do not interpolate.
For example, see page 198.
From: California Natural Gasoline Association Bulletin TS-402.

TABLE XXXVIII

F_{PV}

40° F. – 180° F.

Fpv Base Temp. for 60-64°F.	TEMPERATURE °F. 40	50	55 to 59	65	70	75	80	85	90	100	110	125	140	160	180
1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.001	1.000	1.000
1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.002	1.001	1.001	1.001	1.001	1.001
1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002	1.002	1.002	1.002	1.001	1.001
1.004	1.005	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003	1.003	1.003	1.003	1.002	1.002	1.002
1.005	1.006	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.004	1.003	1.003	1.003	1.002	1.002
1.006	1.007	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.005	1.004	1.004	1.004	1.004	1.003	1.003
1.007	1.008	1.008	1.007	1.007	1.007	1.006	1.006	1.006	1.006	1.005	1.005	1.005	1.004	1.004	1.003
1.008	1.009	1.009	1.008	1.008	1.008	1.007	1.007	1.007	1.007	1.006	1.006	1.005	1.005	1.004	1.004
1.009	1.010	1.010	1.009	1.009	1.008	1.008	1.008	1.008	1.007	1.007	1.006	1.006	1.006	1.005	1.004
1.010	1.011	1.011	1.010	1.010	1.009	1.009	1.009	1.009	1.008	1.008	1.007	1.007	1.006	1.006	1.005
1.011	1.012	1.012	1.011	1.011	1.010	1.010	1.010	1.010	1.009	1.009	1.008	1.007	1.007	1.006	1.005
1.012	1.013	1.013	1.012	1.012	1.011	1.011	1.011	1.010	1.010	1.009	1.009	1.008	1.007	1.007	1.006
1.013	1.015	1.014	1.013	1.013	1.012	1.012	1.012	1.011	1.011	1.010	1.009	1.009	1.008	1.007	1.006
1.014	1.016	1.015	1.014	1.014	1.013	1.013	1.012	1.012	1.012	1.011	1.010	1.009	1.009	1.008	1.007
1.015	1.017	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.012	1.012	1.011	1.010	1.009	1.008	1.007
1.016	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.014	1.013	1.013	1.012	1.011	1.010	1.009	1.008
1.017	1.019	1.018	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.013	1.012	1.012	1.011	1.009	1.008
1.018	1.020	1.019	1.019	1.018	1.017	1.016	1.016	1.015	1.015	1.014	1.013	1.012	1.011	1.010	1.009
1.019	1.021	1.020	1.020	1.018	1.018	1.017	1.017	1.016	1.016	1.015	1.014	1.013	1.012	1.010	1.009
1.020	1.022	1.021	1.021	1.019	1.019	1.018	1.018	1.017	1.017	1.016	1.015	1.013	1.012	1.011	1.009
1.021	1.023	1.022	1.022	1.020	1.020	1.019	1.019	1.018	1.017	1.016	1.015	1.014	1.013	1.011	1.010
1.022	1.025	1.023	1.023	1.021	1.021	1.020	1.020	1.019	1.018	1.017	1.016	1.015	1.013	1.012	1.010
1.023	1.026	1.024	1.024	1.022	1.022	1.021	1.020	1.020	1.019	1.018	1.017	1.016	1.014	1.012	1.011
1.024	1.027	1.026	1.025	1.023	1.022	1.022	1.021	1.020	1.020	1.019	1.017	1.016	1.015	1.013	1.012
1.025	1.028	1.027	1.026	1.024	1.023	1.022	1.022	1.021	1.020	1.019	1.018	1.016	1.015	1.013	1.012
1.026	1.029	1.028	1.027	1.025	1.024	1.023	1.022	1.022	1.021	1.020	1.018	1.017	1.015	1.013	1.012
1.027	1.030	1.029	1.028	1.026	1.025	1.024	1.023	1.023	1.022	1.020	1.019	1.017	1.015	1.014	1.013
1.028	1.032	1.030	1.029	1.027	1.026	1.025	1.024	1.023	1.022	1.021	1.019	1.018	1.016	1.014	1.013
1.029	1.033	1.031	1.030	1.028	1.027	1.026	1.025	1.024	1.023	1.021	1.020	1.018	1.016	1.015	1.014
1.030	1.034	1.032	1.031	1.029	1.028	1.026	1.026	1.025	1.024	1.022	1.021	1.019	1.017	1.015	1.014
1.031	1.036	1.034	1.032	1.030	1.029	1.028	1.027	1.026	1.025	1.023	1.021	1.019	1.017	1.015	1.014
1.032	1.037	1.035	1.033	1.031	1.030	1.029	1.028	1.027	1.025	1.024	1.021	1.020	1.018	1.015	1.014
1.033	1.038	1.036	1.034	1.032	1.031	1.029	1.028	1.028	1.026	1.024	1.022	1.020	1.018	1.016	1.015
1.034	1.039	1.037	1.035	1.033	1.032	1.030	1.029	1.029	1.027	1.025	1.023	1.021	1.018	1.016	1.015
1.035	1.040	1.038	1.036	1.034	1.033	1.031	1.030	1.029	1.028	1.026	1.024	1.021	1.019	1.017	1.015
1.036	1.041	1.039	1.037	1.035	1.033	1.032	1.031	1.030	1.028	1.026	1.024	1.022	1.019	1.017	1.015
1.037	1.042	1.040	1.038	1.036	1.034	1.033	1.032	1.031	1.029	1.027	1.025	1.022	1.020	1.018	1.016
1.038	1.043	1.041	1.039	1.037	1.035	1.034	1.033	1.032	1.030	1.028	1.025	1.023	1.021	1.018	1.016
1.039	1.044	1.042	1.040	1.037	1.036	1.035	1.033	1.032	1.030	1.028	1.026	1.024	1.021	1.019	1.017
1.040	1.045	1.043	1.041	1.038	1.037	1.036	1.034	1.033	1.031	1.029	1.027	1.024	1.022	1.019	1.017

NOTE: Each heading is inclusive to next higher heading. Do not interpolate.

EXAMPLE: To obtain Fpv for temperatures other than 60° to 64° F., inclusive, select the base factor from left-hand column and obtain factor from desired temperature column. Assume base factor 1.039 (same as example, page 198) and for temperatures of 85° to 89° F., inclusive, use 85.

For these conditions Fpv for gauge pressure 180 to 184 lbs., inclusive, specific gravity .900 to .904, inclusive, and temperature 85° to 89° F., inclusive, is 1.032.

From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 202

TABLE XXXVIII — *Continued*

F_{PV}

40° F.-180° F.

F_{PV} Base Temp. for 60-64°F	TEMPERATURE °F.														
	40	50	55 to 59	65	70	75	80	85	90	100	110	125	140	160	180
1.041	1.046	1.044	1.043	1.039	1.038	1.037	1.035	1.034	1.032	1.030	1.027	1.025	1.022	1.020	1.018
1.042	1.048	1.045	1.044	1.040	1.039	1.037	1.036	1.035	1.033	1.031	1.028	1.025	1.023	1.020	1.018
1.043	1.049	1.046	1.045	1.041	1.040	1.038	1.037	1.036	1.034	1.032	1.029	1.026	1.023	1.021	1.018
1.044	1.050	1.047	1.046	1.042	1.041	1.039	1.038	1.037	1.034	1.032	1.029	1.027	1.024	1.022	1.019
1.045	1.051	1.049	1.047	1.043	1.042	1.040	1.039	1.037	1.035	1.033	1.030	1.027	1.024	1.022	1.019
1.046	1.052	1.050	1.048	1.044	1.043	1.041	1.040	1.038	1.036	1.034	1.031	1.028	1.025	1.022	1.020
1.047	1.053	1.051	1.049	1.045	1.044	1.042	1.041	1.039	1.037	1.034	1.031	1.028	1.025	1.023	1.020
1.048	1.055	1.052	1.050	1.046	1.044	1.043	1.041	1.040	1.038	1.035	1.032	1.029	1.026	1.023	1.021
1.049	1.056	1.053	1.051	1.047	1.045	1.044	1.042	1.041	1.039	1.036	1.033	1.030	1.026	1.024	1.021
1.050	1.057	1.054	1.052	1.048	1.046	1.045	1.043	1.042	1.040	1.037	1.034	1.030	1.027	1.024	1.022
1.051	1.058	1.055	1.053	1.049	1.047	1.046	1.044	1.042	1.040	1.037	1.034	1.031	1.028	1.025	1.022
1.052	1.059	1.056	1.054	1.050	1.048	1.046	1.045	1.043	1.041	1.038	1.035	1.032	1.028	1.025	1.023
1.053	1.060	1.057	1.055	1.051	1.049	1.047	1.046	1.044	1.042	1.039	1.036	1.032	1.029	1.026	1.023
1.054	1.062	1.058	1.056	1.052	1.050	1.048	1.046	1.045	1.042	1.040	1.036	1.032	1.029	1.026	1.024
1.055	1.063	1.059	1.057	1.053	1.051	1.049	1.047	1.046	1.043	1.040	1.037	1.033	1.030	1.027	1.024
1.056	1.064	1.060	1.058	1.054	1.052	1.050	1.048	1.046	1.044	1.041	1.037	1.034	1.030	1.027	1.024
1.057	1.065	1.061	1.059	1.055	1.053	1.051	1.049	1.047	1.045	1.042	1.038	1.035	1.031	1.028	1.025
1.058	1.066	1.062	1.060	1.056	1.054	1.052	1.050	1.048	1.045	1.042	1.039	1.035	1.031	1.028	1.025
1.059	1.067	1.063	1.061	1.057	1.055	1.053	1.051	1.049	1.046	1.043	1.040	1.036	1.032	1.029	1.026
1.060	1.068	1.064	1.062	1.058	1.055	1.053	1.051	1.050	1.047	1.044	1.040	1.036	1.032	1.029	1.026
1.061	1.070	1.066	1.063	1.059	1.056	1.054	1.052	1.051	1.048	1.045	1.041	1.037	1.033	1.030	1.027
1.062	1.071	1.067	1.064	1.060	1.057	1.055	1.053	1.051	1.049	1.045	1.041	1.037	1.034	1.031	1.027
1.063	1.072	1.068	1.065	1.061	1.058	1.056	1.054	1.052	1.050	1.046	1.042	1.038	1.034	1.031	1.028
1.064	1.073	1.069	1.066	1.061	1.059	1.057	1.055	1.053	1.050	1.047	1.043	1.038	1.035	1.031	1.028
1.065	1.074	1.071	1.067	1.062	1.060	1.058	1.055	1.054	1.051	1.048	1.043	1.039	1.035	1.032	1.029
1.066	1.076	1.072	1.069	1.063	1.061	1.059	1.057	1.055	1.052	1.048	1.044	1.040	1.036	1.032	1.029
1.067	1.077	1.073	1.070	1.064	1.062	1.060	1.058	1.056	1.053	1.049	1.045	1.041	1.036	1.033	1.030
1.068	1.078	1.074	1.071	1.065	1.063	1.061	1.058	1.056	1.053	1.050	1.045	1.041	1.037	1.033	1.030
1.069	1.079	1.075	1.072	1.066	1.064	1.062	1.059	1.057	1.054	1.051	1.046	1.042	1.038	1.034	1.030
1.070	1.081	1.076	1.073	1.067	1.065	1.062	1.060	1.058	1.055	1.051	1.046	1.042	1.038	1.034	1.031
1.071	1.082	1.077	1.074	1.068	1.066	1.063	1.061	1.059	1.055	1.052	1.047	1.043	1.039	1.035	1.031
1.072	1.083	1.078	1.075	1.069	1.067	1.064	1.062	1.059	1.056	1.052	1.048	1.043	1.039	1.035	1.032
1.073	1.084	1.079	1.076	1.070	1.068	1.065	1.063	1.060	1.057	1.053	1.048	1.044	1.039	1.035	1.032
1.074	1.085	1.080	1.077	1.071	1.068	1.066	1.063	1.061	1.058	1.054	1.049	1.045	1.040	1.036	1.033
1.075	1.086	1.081	1.078	1.072	1.069	1.067	1.064	1.062	1.059	1.055	1.050	1.046	1.041	1.037	1.033
1.076	1.087	1.082	1.079	1.073	1.070	1.068	1.065	1.063	1.059	1.056	1.051	1.047	1.042	1.038	1.034
1.077	1.088	1.083	1.080	1.074	1.071	1.069	1.066	[illegible]	[illegible]	1.056	[illegible]	1.047	1.042	1.038	1.034
1.078	[illegible]	1.084	1.081	1.075	1.072	[illegible]	1.067	[illegible]	[illegible]	1.057	1.052	1.048	1.043	[illegible]	[illegible]
1.079	[illegible]	1.085	1.082	1.076	1.073	1.070	[illegible]	[illegible]	1.062	[illegible]	1.053	1.048	[illegible]	[illegible]	[illegible]
1.080	1.092	1.086	1.083	1.077	1.074	1.071	1.068	1.066	1.062	1.059	1.054	1.049	1.044	1.040	1.036
1.081	1.093	1.087	1.084	1.078	1.075	1.072	1.069	1.067	1.063	1.060	1.055	1.050	1.045	1.040	1.036
1.082	[illegible]	1.088	1.085	1.079	1.076	1.073	1.070	1.068	[illegible]	1.061	1.056	1.050	[illegible]	[illegible]	1.037
1.083	[illegible]	[illegible]	1.086	1.080	1.077	[illegible]	1.071	[illegible]	[illegible]	1.062	[illegible]	1.051	[illegible]	[illegible]	1.037
1.084	1.097	[illegible]	1.087	1.081	1.078	[illegible]	1.072	[illegible]	[illegible]	1.062	1.057	1.052	[illegible]	1.042	1.038
1.085	1.098	1.092	1.088	1.082	1.079	1.076	1.073	1.071	1.067	1.063	1.057	1.052	1.047	1.042	1.038
1.086	[illegible]	1.093	1.089	1.083	1.079	1.077	1.074	1.071	1.068	1.064	1.058	1.053	1.048	1.043	1.038
1.087	[illegible]	[illegible]	1.090	[illegible]	1.080	1.078	[illegible]	1.072	[illegible]	[illegible]	[illegible]	1.053	1.048	[illegible]	[illegible]
1.088	[illegible]	[illegible]	1.091	[illegible]	1.081	[illegible]	[illegible]	1.073	[illegible]	1.065	[illegible]	1.054	[illegible]	[illegible]	[illegible]
1.089	[illegible]	1.096	1.092	[illegible]	1.082	[illegible]	[illegible]	1.074	1.070	[illegible]	1.060	[illegible]	[illegible]	[illegible]	1.039
1.090	1.103	1.097	1.093	1.087	1.083	1.080	[illegible]	1.075	1.071	1.067	[illegible]	[illegible]	[illegible]	[illegible]	1.040
1.091	[illegible]	1.098	[illegible]	1.088	1.084	[illegible]	1.078	1.076	[illegible]	1.067	[illegible]	1.056	[illegible]	[illegible]	1.040
1.092	[illegible]	1.099	[illegible]	[illegible]	1.085	1.082	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.056	1.051	[illegible]	[illegible]
1.093	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.057	[illegible]	[illegible]	[illegible]
1.094	[illegible]	[illegible]	[illegible]	[illegible]	1.087	[illegible]	[illegible]	[illegible]	[illegible]	1.070	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.095	[illegible]	1.102	[illegible]	[illegible]	1.088	1.085	1.082	[illegible]	[illegible]	1.070	[illegible]	1.058	1.052	1.047	1.042
1.096	[illegible]	1.103	1.099	1.092	1.089	1.085	[illegible]	1.080	1.076	[illegible]	[illegible]	[illegible]	[illegible]	1.047	1.042
1.097	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.098	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.087	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.099	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1.100	[illegible]	1.108	1.103	[illegible]	1.093	1.089	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

NOTE: Each heading is inclusive to next higher heading. Do not interpolate.
For example, see page 291.
From: California Natural Gasoline Association Bulletin TS-402.

TABLE XXXIX

Corrections to Supercompressibility Factor, F_P

AIR CORRECTION

Sp. Gr.	% Air	35		135		235		335		435	
		30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°
.550 to .649	1	....	....	....	....	....	....	.001	.000	.001	.001
	2	....	....	.001	....	.001	.001	.002	.001	.002	.001
	3	.001	....	.001	.001	.002	.001	.002	.002	.003	.002
	4	.001	.001	.002	.001	.002	.001	.003	.002	.005	.003
	5	.001	.001	.002	.001	.003	.002	.004	.003	.006	.004
	6	.001	.001	.002	.002	.004	.002	.005	.004	.007	.004
	7	.001	.001	.003	.002	.004	.003	.006	.004	.008	.005
	8	.001	.001	.003	.002	.005	.003	.007	.005	.009	.006
.650 to .749	1	....	....	....	....	.001	....	.001	.001	.001	.001
	2	....	....	.001	....	.001	.001	.002	.001	.003	.002
	3	.001	....	.001	.001	.002	.001	.002	.002	.004	.002
	4	.001	.001	.002	.001	.002	.002	.003	.003	.005	.003
	5	.001	.001	.002	.002	.003	.002	.004	.003	.006	.004
	6	.001	.001	.002	.002	.004	.003	.005	.004	.008	.005
	7	.001	.001	.003	.002	.005	.003	.006	.005	.009	.006
	8	.001	.001	.003	.003	.005	.004	.007	.005	.010	.007
.750 to .849	1	....	....	....	....	.001	.000	.001	.001	.001	.001
	2	....	....	.001	.001	.001	.001	.002	.001	.003	.002
	3	.001	....	.001	.001	.002	.001	.003	.002	.004	.003
	4	.001	.001	.002	.001	.003	.002	.004	.003	.006	.004
	5	.001	.001	.002	.002	.004	.003	.005	.004	.007	.005
	6	.001	.001	.003	.002	.004	.003	.006	.005	.009	.006
	7	.001	.001	.003	.002	.005	.004	.007	.005	.010	.007
	8	.001	.001	.004	.003	.006	.005	.009	.006	.012	.008
.850 to .949	1	....	....	....	....	.001	....	....	....	....	....
	2	....	....	.001	.001	.001	.001	....	....	....	....
	3	.001	....	.002	.001	.002	.002	....	....	....	....
	4	.001	.001	.002	.002	.003	.002	....	....	....	....
	5	.001	.001	.003	.002	.004	.003	....	....	....	....
	6	.001	.001	.003	.002	.005	.004	....	....	....	....
	7	.001	.001	.004	.003	.005	.004	....	....	....	....
	8	.002	.001	.004	.003	.006	.005	....	....	....	....
.950 to 1.04	1	....	....	.001	....	.001	.001	....	....	....	....
	2	....	....	.001	.001	.002	.001	....	....	....	....
	3	.001	.001	.002	.001	.002	.002	....	....	....	....
	4	.001	.001	.002	.002	.003	.003	....	....	....	....
	5	.001	.001	.003	.002	.004	.004	....	....	....	....
	6	.001	.001	.004	.002	.005	.004	....	....	....	....
	7	.002	.001	.004	.003	.006	.005	....	....	....	....
	8	.002	.001	.005	.003	.006	.006	....	....	....	....

Note: Each heading is inclusive to next higher heading. Do not interpolate.
The above corrections for given amounts of air and carbon dioxide are deductible from the corrected supercompressibility factors determined from Tables XXXVII and XXXVIII.
From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 204

TABLE XXXIX — *Continued*

Corrections to Supercompressibility Factor, F_{PV}

AIR CORRECTION

Sp. Gr.	% Air	Pressure Pounds Gauge 35		135		235		335		435	
		30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°
1.05 to 1.14	1	....	....	.001	....	....	....	....	....	....	....
	2	.001	....	.001	.001	....	....	....	....	....	....
	3	.001	.001	.002	.001	....	....	....	....	....	....
	4	.001	.001	.003	.002	....	....	....	....	....	....
	5	.001	.001	.003	.002	....	....	....	....	....	....
	6	.002	.001	.004	.003	....	....	....	....	....	....
	7	.002	.001	.005	.003	....	....	....	....	....	....
	8	.002	.001	.005	.004	....	....	....	....	....	....
1.15 to 1.24	1	....	....	.001	....	....	....	....	....	....	....
	2	.001	....	.002	.001	....	....	....	....	....	....
	3	.001	.001	.002	.002	....	....	....	....	....	....
	4	.001	.001	.003	.002	....	....	....	....	....	....
	5	.001	.001	.004	.003	....	....	....	....	....	....
	6	.002	.001	.004	.003	....	....	....	....	....	....
	7	.002	.001	.005	.004	....	....	....	....	....	....
	8	.002	.001	.006	.004	....	....	....	....	....	....
1.25 to 1.34	1	....	....	....	....	....	....	....	....	....	....
	2	.001	....	....	....	....	....	....	....	....	....
	3	.001	.001	....	....	....	....	....	....	....	....
	4	.001	.001	....	....	....	....	....	....	....	....
	5	.002	.001	....	....	....	....	....	....	....	....
	6	.002	.001	....	....	....	....	....	....	....	....
	7	.002	.001	....	....	....	....	....	....	....	....
	8	.002	.001	....	....	....	....	....	....	....	....
1.35 to 1.44	1	.001	....	....	....	....	....	....	....	....	....
	2	.001	....	....	....	....	....	....	....	....	....
	3	.001	.001	....	....	....	....	....	....	....	....
	4	.002	.001	....	....	....	....	....	....	....	....
	5	.002	.001	....	....	....	....	....	....	....	....
	6	.002	.001	....	....	....	....	....	....	....	....
	7	.002	.001	....	....	....	....	....	....	....	....
	8	.002	.002	....	....	....	....	....	....	....	....

NOTE: Each heading is inclusive to next higher heading. Do not interpolate.

The above corrections for given amounts of air and carbon dioxide are deductible from the corrected superexpansibility factors determined from Tables XXXVII and XXXVIII.

From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 205

TABLE XXXIX — *Continued*

Corrections to Supercompressibility Factor, F_{PV}

CARBON DIOXIDE CORRECTION

Sp. Gr.	% CO_2	Pressure Pounds Gauge 35		135		235		335		435	
		30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°
	1	....	....	....	....	....	....	.001	....	.001	.001
	2	....	....	.001	.001	.001	.001	.001	.001	.002	.001
	3	.001	.001	.001	.001	.001	.001	.002	.001	.002	.002
.550	4	.001	.001	.001	.001	.002	.002	.002	.002	.003	.002
to	5	.001	.001	.002	.002	.002	.002	.003	.002	.004	.003
.649	6	.001	.001	.002	.002	.003	.002	.003	.002	.004	.003
	7	.001	.001	.003	.002	.004	.002	.004	.003	.005	.003
	8	.002	.001	.003	.002	.004	.002	.005	.003	.006	.004
	1	....	....	....	....	.001	.001	.001	.001	.002	.001
	2	....	....	.001	....	.001	.001	.002	.002	.003	.002
	3	.001	.001	.001	.001	.002	.002	.003	.002	.004	.003
.650	4	.001	.001	.002	.001	.003	.002	.004	.003	.006	.004
to	5	.001	.001	.002	.002	.003	.003	.005	.004	.007	.004
.749	6	.001	.001	.003	.002	.004	.003	.006	.004	.008	.005
	7	.002	.001	.003	.002	.005	.004	.006	.005	.009	.006
	8	.002	.001	.004	.003	.005	.004	.007	.005	.010	.007
	1	....	....	....	....	.001	.001	.001	.001	.002	.001
	2	....	....	.001	.001	.002	.001	.003	.002	.004	.003
	3	.001	.001	.001	.001	.003	.002	.004	.003	.005	.004
.750	4	.001	.001	.002	.002	.003	.003	.005	.004	.006	.005
to	5	.001	.001	.002	.002	.004	.003	.007	.005	.008	.006
.849	6	.002	.001	.003	.003	.005	.004	.008	.006	.010	.007
	7	.002	.001	.004	.003	.006	.005	.009	.007	.011	.008
	8	.002	.002	.004	.003	.007	.005	.010	.007	.013	.009
	1	....	....	.001	.001	.001	.001	....	....	....	....
	2	.001	.001	.001	.001	.002	.002	....	....	....	....
	3	.001	.001	.002	.001	.003	.002	....	....	....	....
.850	4	.001	.001	.003	.002	.004	.003	....	....	....	....
to	5	.001	.001	.004	.002	.005	.004	....	....	....	....
.949	6	.002	.001	.004	.003	.006	.005	....	....	....	....
	7	.002	.002	.005	.003	.007	.005	....	....	....	....
	8	.002	.002	.006	.004	.008	.006	....	....	....	....
	1	....	....	.001	.001	.001	.001	....	....	....	....
	2	.001	.001	.001	.001	.002	.002	....	....	....	....
	3	.001	.001	.002	.002	.004	.003	....	....	....	....
.950	4	.001	.001	.003	.002	.005	.003	....	....	....	....
to	5	.002	.001	.004	.003	.006	.004	....	....	....	....
1.04	6	.002	.002	.004	.003	.008	.005	....	....	....	....
	7	.002	.002	.005	.004	.009	.006	....	....	....	....
	8	.003	.002	.006	.004	.011	.007	....	....	....	....

Note: Each heading is inclusive to next higher heading. Do not interpolate.

The above corrections for given amounts of air and carbon dioxide are deductible from the corrected supercompressibility factors determined from Tables XXXVII and XXXVIII.

From: California Natural Gasoline Association Bulletin TS-402.

Continued on page 206

TABLE XXXIX — *Continued*

Corrections to Supercompressibility Factor, F_{PV}

CARBON DIOXIDE CORRECTION

Sp. Gr.	% CO_2	Pressure Pounds Gauge 35		135		235		335		435	
		30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°	30°-89°	90°-149°
1.05 to 1.14	1	....	....	.001	.001	....	....	....	....	....	....
	2	.001	.001	.002	.001	....	....	....	....	....	....
	3	.001	.001	.003	.002	....	....	....	....	....	....
	4	.001	.001	.003	.003	....	....	....	....	....	....
	5	.002	.002	.004	.003	....	....	....	....	....	....
	6	.002	.002	.005	.004	....	....	....	....	....	....
	7	.003	.002	.006	.004	....	....	....	....	....	....
	8	.003	.002	.007	.005	....	....	....	....	....	....
1.15 to 1.24	1	....	....	.001	.001	....	....	....	....	....	....
	2	.001	.001	.002	.001	....	....	....	....	....	....
	3	.001	.001	.003	.002	....	....	....	....	....	....
	4	.002	.001	.004	.003	....	....	....	....	....	....
	5	.002	.002	.005	.004	....	....	....	....	....	....
	6	.002	.002	.007	.004	....	....	....	....	....	....
	7	.003	.002	.008	.005	....	....	....	....	....	....
	8	.003	.003	.009	.006	....	....	....	....	....	....
1.25 to 1.34	1	....	.001	....	....	....	....	....	....	....	....
	2	.001	.001	....	....	....	....	....	....	....	....
	3	.001	.001	....	....	....	....	....	....	....	....
	4	.002	.002	....	....	....	....	....	....	....	....
	5	.002	.002	....	....	....	....	....	....	....	....
	6	.003	.002	....	....	....	....	....	....	....	....
	7	.003	.003	....	....	....	....	....	....	....	....
	8	.004	.003	....	....	....	....	....	....	....	....
1.35 to 1.44	1	.001	....	....	....	....	....	....	....	....	....
	2	.001	.001	....	....	....	....	....	....	....	....
	3	.001	.001	....	....	....	....	....	....	....	....
	4	.002	.001	....	....	....	....	....	....	....	....
	5	.002	.002	....	....	....	....	....	....	....	....
	6	.003	.002	....	....	....	....	....	....	....	....
	7	.003	.002	....	....	....	....	....	....	....	....
	8	.004	.003	....	....	....	....	....	....	....	....

NOTE: Each heading is inclusive to next higher heading. Do not interpolate.

The above corrections for given amounts of air and carbon dioxide are deductible from the corrected superexpansibility factors determined from Tables XXXVII and XXXVIII.

From California Natural Gasoline Association Bulletin TS-402.

NOMENCLATURE (GAS)

Symbols Applicable only to Report No. 1 Coefficients

C = corrected coefficient (cu. ft. per hour).

C_a = coefficient for free air at pressure base 0 lbs. above 14.4 lbs. per square inch, temperature base 60°F., flowing temperature 60°F. (cubic feet per hour for flange taps).

C_{ap} = coefficient for free air at pressure base 0 lbs. above 14.4 lbs. per square inch, temperature base 60°F., flowing temperature 60°F. (cubic feet per hour for pipe taps).

C_u = the figure which, multiplied by the reading of the differential pen times the reading of the static pen on a 0–10 square root chart, gives rate of flow in cubic feet per hour.

E = a function of the ratio of orifice to pipe diameter, used as a compensating factor in the flow equation. Ratio of actual to hypothetical flow (no units).

K = a constant dependent upon units of measurement, page 112.

$S = \frac{Ed^2}{D^2}$ (see tables). S_f for flange, pages 115-124. S_p for pipe connections, pages 125-134.

Symbols Applicable only to Report No. 2 Coefficients

C' = corrected coefficient including all flow factors except $\sqrt{hP}$.

C'' = corrected coefficient including all flow factors except $\sqrt{hP}$ and F_r.

F_b = basic flow factor for gas.

F_r = Reynolds number factor $= 1 + \frac{r}{\sqrt{hP}}$.

k = ratio of specific heats.

r = factor used to interpolate for F_r.

x = ratio of differential to upstream static pressure in same units.

Y = expansion factor.

General Nomenclature

D = internal diameter of line (inches).

d = orifice diameter (inches).

F_g = correction for specific gravity, values of which may be found in the 0 lbs. pressure base column of Table XXI, pages 98–102.

F_m = moisture correction factor, page 93.

F_p = correction factor for pressure base, values of which will be found in Table XXII, page 103.

F_t = correction factor for flowing temperature, page 104.

F_{gp} = correction factor for gravity and pressure base. $F_{gp} = F_g F_p$, pages 98-102.

F_{pv} = supercompressibility factor, pages 196-206.

F_{tb} = correction factor for temperature base, page 105.

G = specific gravity of flowing gas relative to air at the same temperature and pressure (no units).

g = gravitational acceleration (taken as 32.16) (in feet per second per second).
G_n = new specific gravity relative to air at same temperature and pressure.
G_o = specific gravity on which the original coefficient was based (relative to air at the same temperature and pressure).
h = differential pressure (inches of water).
h_m = differential range of meter (inches of water).
P = absolute static pressure of flow (lbs. per sq. in.).
P_1 = upstream absolute static pressure, in lbs./sq. in.
P_2 = downstream absolute static pressure, in lbs./sq. in.
P_3 = intermediate or modified absolute static pressure, in lbs./sq. in.
P_B = absolute storage pressure on which measurement is based, lbs. per sq. in.
P_{Bn} = new pressure base (lbs. per sq. in. absolute).
P_{Bo} = pressure base of original coefficient (lbs. per sq. in. absolute).
P_m = absolute static pressure range of gauge in pounds per square inch.
P_{wb} = water vapor pressure at base temperature, pounds per square inch absolute.
P_{wf} = water vapor pressure at flowing temperature, pounds per square inch absolute.
Q = volume rate of flow of gas (in cubic feet per hour).
Q_m = flow corresponding to maximum reading of both static and differential.
R = 10.71.
R_b = % relative humidity at base conditions as specified by contract ÷ 100.
R_f = % relative humidity of flowing gas ÷ 100.
s = speed of flowing gas at plane of downstream tap (in feet per second).
T = absolute temperature, °Rankine (°F. + 460).
T_B = absolute storage temperature on which measurement is based, °Rankine.
T_{Bn} = new temperature base, absolute scale, °Rankine.
T_{Bo} = temperature base of original coefficient, absolute scale, °Rankine.
T_f = absolute temperature of flowing gas, °Rankine.
T_{fn} = new absolute temperature of flowing gas, °Rankine.
T_{fo} = absolute temperature on which the original coefficient is based, °Rankine.
V' = volume in cubic feet.
w_m = density of mercury, in lbs./cu. ft.
w_s = density of gas or liquid which displaces the mercury, in lbs./cu. ft.
w = density of vapor at flowing conditions, in lbs./cu. ft.
Z = ratio of theoretical density to actual density.
μ = absolute viscosity, poises.

SUMMARY OF EQUATIONS (GAS)

Equations Applicable only to Report No. 1 Coefficients

51 $C_a = KSD^2$

52 $S_p = .58925\frac{d^2}{D^2} + .2725\frac{d^3}{D^3} - .825\frac{d^4}{D^4} + 1.75\frac{d^5}{D^5}$ . . . (Pipe taps)

53 $S_f = .606\frac{d^2}{D^2} + 1.25\frac{d^2}{D^2}\left(\frac{d}{D} - .41\right)^2$ above $\frac{d}{D} = .41$ (Flange taps)

54 $Q = C_a \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv} \times \sqrt{h} \times \sqrt{P}$ (Flange taps)

55 $Q = C_{ap} \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv} \times \sqrt{h} \times \sqrt{P}$ (Pipe taps)

56 $C = C_a \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv}$ . . . . . . (Flange taps)

57 $C = C_{ap} \times F_{gp} \times F_t \times F_{tb} \times F_m \times F_{pv}$ . . . . (Pipe taps)

63 S

64 $S = \frac{Q_m}{KD^2 F_{gp} F_t F_{tb} F_{pv} F_m \sqrt{h_m P}}$

65 $\frac{100\, C_u}{KD^2 F_{gp} F_t F_{tb} F_{pv} F_m \sqrt{h_m P}}$

66 $Q = C\sqrt{hP}$

Part II

To Compute Gas Flow Using A.G.A. Report No. 1 Data

Flow Equations

$$Q = C_a \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \times \sqrt{h} \times \sqrt{P} \text{ (Flange Taps).}$$

$$Q = C_{ap} \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \times \sqrt{h} \times \sqrt{P} \text{ (Pipe Taps).}$$

Basic Coefficients

◀ **P. 94-95....** C_a = basic orifice coefficient (Flange Taps).

◀ **P. 96-97....** C_{ap} = basic orifice coefficient (Pipe Taps).

Corrected Coefficient Equations

$$C = C_a \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \text{ (Flange Taps).}$$

$$C = C_{ap} \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m \text{ (Pipe Taps).}$$

Factors

◀ **P. 98-102...** F_{gp} = combined factor for specific gravity and pressure base.

◀ **P. 105 .....** F_{tb} = temperature base factor.

◀ **P. 104 .....** F_t = flowing temperature factor.

◀ **P. 196-206..** F_{pv} = supercompressibility factor.

◀ **P. 93 ......** F_m = correction for moisture.

Multipliers

◀ **P. 150 .....** $\sqrt{h}$ = multiplier for differential.

◀ **P. 151-153..** $\sqrt{P}$ = multiplier for static pressure.

Factors Used in Equations on Page 209

◀ **P 115-124..** S_f for flange taps.

◀ **P. 125-134..** S_p for pipe taps.

◀ **P. 112 .....** K = constant for flow in cubic feet per hour at standard conditions.

SUMMARY OF EQUATIONS (GAS)

General Equations

58 $F_t = \sqrt{\dfrac{T_{fo}}{T_{fn}}}$

59 $F_{tb} = \dfrac{T_{Bn}}{T_{Bo}}$

60 $F_{gp} = \dfrac{P_{Bo}}{P_{Bn}}\sqrt{\dfrac{G_o}{G_n}}$

61 $F_m = \dfrac{P - R_f\,P_{wf}}{P} \times \dfrac{P_B}{P_B - R_b\,P_{wb}}$

62 $F_m = \dfrac{P_B}{P_B - R_b\,P_{wb}}$ if flowing gas is dry

74 $F_{pv} = \dfrac{Z_b}{\sqrt{Z_f}}$

75 $w = \dfrac{\text{Molecular Weight}}{10.71} \times \dfrac{P}{ZT}$

76 $B' = \sqrt{1 - .00118\,w_s}$

Equations Applicable only to Report No. 2 Coefficients

67 $Y_1 = 1 - \left[0.41 + 0.35\left(\dfrac{d}{D}\right)^4\right]\dfrac{x}{k}$ . . . . (Flange taps)

68 $Y_1 = 1 - \left[0.333 + 1.145\left(\dfrac{d^2}{D^2} + 0.75\,\dfrac{d^5}{D^5} + 12\,\dfrac{d^{13}}{D^{13}}\right)\right]\dfrac{x}{k}$ (Pipe taps)

69 $Y_2 = Y_1\sqrt{\dfrac{1}{1 - x}}$

70 $P_3 = P_2 + b(P_1 - P_2)$

71 $b = 27.7\,(Y_2^2 - 1) \div h/P_2$

72 $C'' = F_b \times Y \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m$

73 $Q = C''\sqrt{hP} + C''\,r$

77 $Q = C'\sqrt{hP}$

78 $C' = F_b \times F_r \times Y \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m$

79 $F_r = 1 + \dfrac{r}{\sqrt{hP}}$

Part II

To Compute Gas Flow Using A.G.A. Report No. 2 Data

Flow Equation

$$Q = C'\sqrt{hP}.$$

Corrected Coefficient Equation

$$C' = F_b \times F_r \times Y \times F_{gp} \times F_{tb} \times F_t \times F_{pv} \times F_m.$$

Factors

P. 180-18?.. F_b for flange taps = basic orifice flow factor, cubic feet per hour.

P. 183-18?.. r for flange taps in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$.

P. 185-18?.. Y_2 for flange taps = expansion factor when downstream pressure is used

P. 188-18?.. F_b for pipe taps = basic orifice flow factor, cubic feet per hour.

P. 190-191.. r for pipe taps in formula $F_r = 1 + \frac{r}{\sqrt{hP}}$.

P. 193 ..... Y_1 for pipe taps = expansion factor when upstream pressure is used.

P. 194-19?.. Y_2 for pipe taps = expansion factor when downstream pressure is used

P. 98-102... F_{gp} = combined factor for specific gravity and pressure ba

P. 105 ..... F_{tb} = temperature base factor.

P. 104 ..... F_t = flowing temperature factor.

P. 196-20?.. F_{pv} = supercompressibility factor.

Multipliers

P. 150 ..... $\sqrt{h}$ = multiplier for differential.

P. 151-153.. $\sqrt{P}$ = multiplier for static pressure.

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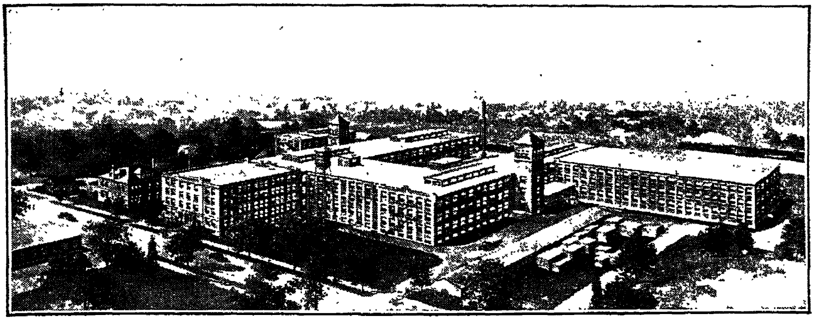

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